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EXERCISES IN PRACTICAL PHYSICS FOR SCHOOLS OF SCIENCE

BY

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PREFACE.

THE volume to which this is a supplement contains a course of experimental work in mensuration, hydrostatics, mechanics, and heat, suitable for first year students in Schools of Science and other institutions in which practical physics finds a place in the curriculum. The only parts of the science of heat included in the first volume are the construction and use of thermometers, thermal conduction, and radiation. These sections are here repeated in order to complete the series of experiments in heat. In addition this book contains instructions for laboratory work in light, sound, magnetism, and electricity, such as may be carried out by second year pupils. The two parts thus provide an elementary course of practical work in the chief branches of physical science.

As in Part I., the characteristics to which we invite the attention of teachers are briefly:

(1) The number and variety of exercises used to exemplify each of the principles dealt with.

(2) The limitation of the text to instructions for the intelligent performance of the experiments and the recognition of the significance of the results obtained.

(3) The number of new and simple experimental devices which, by the courtesy of various teachers, it has been possible to incorporate.

(4) The numerous illustrations showing at a glance the apparatus required and the method of procedure.

Teachers of practical physics may be left to judge for themselves as to the value of these points. Our own ex-

perience in teaching and examining has convinced us that a sound knowledge of any scientific principle is only obtained after many experiments, designed to present it under different aspects, have been performed and studied. It is for this reason that several exercises are given under each division of the subject. When time permits a student ought to perform practically all the exercises, in order to impress upon his mind the principles they exemplify; he should, in fact, regard the exercises as he does the examples in his mathematical books, and work as many of them as he can. But where certain subjects must be studied in the very few hours per week allotted to practical physics it will be necessary for the teacher to make a selection.

The descriptive matter has been curtailed because students only require, in a laboratory manual, instructions to guide them in carrying out experimental work—they can study the theoretical aspects of their laboratory practice from lecture-notes and in text books of general physics.

We are glad of this opportunity of making many grateful acknowledgments—to the teachers whose names are mentioned during the course of the book, for new and ingenious experiments to elucidate particular principles: to Mr. L. M. Jones, B.Sc., St. Dunstan's College, Catford, for very valuable assistance while the sheets were passing through the press, and a number of useful hints and notes which have enabled us to improve several parts of the course; and finally, to Mr. H. E. Hadley, B.Sc., and Mr. E. Edser for reading some of the sections and giving us the benefit of their criticisms.

R. A. G.
A. T. S.

LONDON, *October*, 1899.

CONTENTS.

CHAPTER I.

THERMOMETERS, AND SIMPLE OBSERVATIONS WITH THEM.

1. Construction of a Thermometer.

FIG. 1.—A thermometer in course of construction.

(*a*) OBTAIN a piece of thermometer tubing, about ten inches long, and if you have practised glass-blowing, blow a bulb about $\frac{1}{2}$ inch in diameter at one end. If you cannot do this, it will save time to obtain a tube with a bulb already blown upon it.

Mode of Filling the Bulb and Tube.

(*b*) Gently heat the bulb of the thermometer tube over a flame, and then quickly immerse the open end in alcohol coloured with cochineal

> A small quantity of the spirit enters the bulb to take the place of the air driven out by the heat.

If your thermometer tube has not a cup blown at the open end, like that in Fig. 1, connect the open end with a glass funnel by means of a piece of india-rubber tubing about an inch long. Pour into the cup or funnel sufficient coloured alcohol to fill the bulb. Hold the bulb in a flame (Fig. 2) until nearly all the alcohol is boiled away, then take away the flame. Alcohol will enter the bulb and stem. Repeat the operation until the bulb and stem are filled with the liquid; then disconnect

the funnel or pour the surplus alcohol out of the cup, and let the instrument cool.

Sealing the Tube

(*c*) When the alcohol in the stem has contracted two or three inches, melt the tube near the end in a blow pipe flame, and

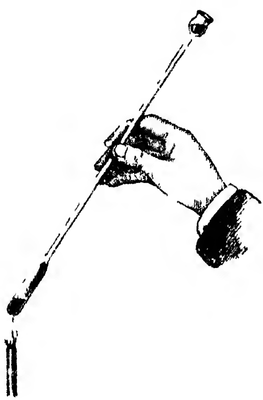


FIG. 2.—Method of filling a thermometer.

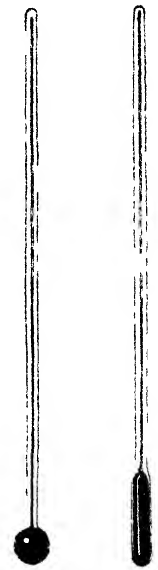


FIG. —Thermometer tubes filled and sealed ready for graduation.

draw it out to a narrow neck about eight inches from the bulb. Immerse the bulb and stem in hot water *not* boiling water and when the alcohol fills the tube, seal the tube quickly by directing a small blow-pipe flame against the narrow neck, and afterwards complete the sealing so as to make the end strong. The final result should be like one of the instruments in Fig. 3

You have now an instrument by means of which the

state of warmth or coldness of a body can be indicated. When it is warmed the liquid in it rises in the tube, and when it is cooled the liquid sinks, so that by noticing the position of the top of the liquid you are able to determine whether the thing in contact with the instrument is warm or cold. Marks or graduations can be made upon the tube to indicate various degrees of warmth, and when this has been done the instrument becomes a *thermometer*, that is, an instrument for the determination of *temperature*, or *intensity of heat*.

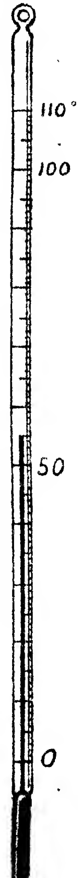


FIG. 4.—A thermometer with Centigrade graduations.

2. Simple Temperature Observations.

(*a*) Examine the thermometer supplied you (Fig. 4). Notice that it is similar to the instrument you have made, but is graduated or marked in a certain manner. The divisions are called *degrees*.

(*b*) Hold a thermometer in your mouth for a short time; find and record the temperature indicated by it. Also place a thermometer under your arm-pit; find and record the temperature there.

(*c*) Let a thermometer hang freely in the air for a short time, and find the temperature of the air indicated by it. Then place the thermometer upon your table, and see whether the same temperature is indicated.

3. Freezing Point of Water.

(*a*) Support a funnel upon one of the rings of your retort-stand, and fill it with

scraps or shavings of ice (Fig. 5). Place the thermometer in the funnel, pack shavings or scraps of ice around it, and notice how the mercury behaves. Observe the exact point at which the mercury ceases to contract. The experiment shows the temperature at which ice melts and water freezes. Repeat the experiment with fresh ice and if possible in a part of the room having a distinctly different temperature.

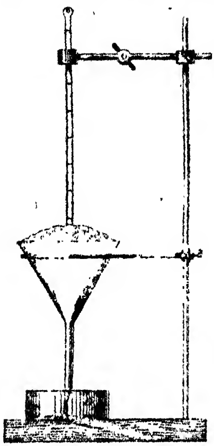


FIG. 5.—Determining the freezing point of a thermometer.

(*b*) Place some small pieces of ice in a beaker of cold water. Well stir the water with the thermometer, and observe its temperature. Gently heat the beaker of water until the ice is melted, stirring all the time. Describe fully the changes of temperature that occur both before and after the ice has melted. You will find that the temperature will not rise until all the ice has melted.

4. Boiling Point of Water.

(*a*) Fit a cork, with two holes through it, into a flask or test-tube (Fig. 6). Half fill the test-tube with water, and push the thermometer through one of the holes in the cork until the bulb is wholly immersed. Into the other hole, fit a piece of glass tubing bent at right-angles. Place the test-tube upon the retort-stand, and observe the division of the thermometer scale level with the top of the mercury. Gently heat the water until it boils, noticing how the mercury is affected throughout the process. See where the mercury stands when the water is boiling, and find whether any difference is produced when the water is boiling

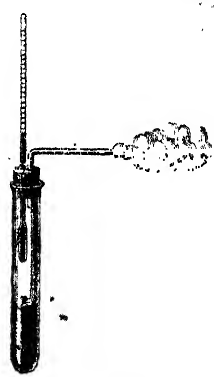


FIG. 6.—Determination of boiling point.

furiously, and when it is boiling gently. Raise the thermometer until the bulb is just above the boiling water, and observe the temperature which it then indicates.

The temperature of boiling water depends upon the pressure of the atmosphere, and therefore varies with the height of the barometer, and with the altitude of the water above sea-level. Under the same conditions, however, the temperature of pure boiling water is the same. The standard conditions are when the water is at sea-level and the barometer stands at a height of 30 inches. The mercury in an accurately graduated thermometer should, if held in boiling water under these conditions, be at the division 100. or 212, according to the system of graduation used. More exact methods of determining the boiling point of a liquid are described in later Exercises.

5. Degrees of Temperature.

The difference of temperature between the boiling point and freezing point of water could be divided into any number of steps, but only two methods of subdivision are in general use. These two thermometric scales are the Centigrade scale and the Fahrenheit scale. A third scale, the Réaumur scale, is used for domestic purposes in Germany, but is not employed in this country. The three scales are shown in Fig. 7.

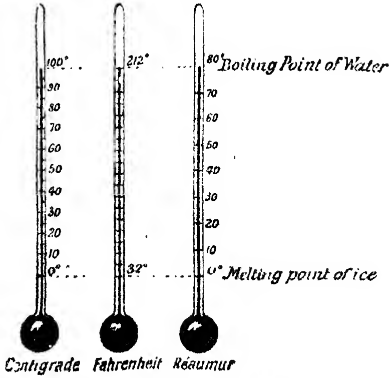


FIG. 7.—Thermometric scales.

The Centigrade Scale.—Here the freezing point is called *zero*, or *no degrees Centigrade*, written 0° C. The boiling point is called *one hundred degrees Centigrade*, and is written 100° C. The space between these two limits is divided into 100 parts, and each division called a *degree Centigrade*.

The Fahrenheit Scale.—On thermometers marked in this way the freezing point is called *thirty-two degrees Fahrenheit*, written 32° F., and the boiling point *two hundred and twelve degrees Fahrenheit*, written 212° F. The space between the two limits is divided into 180 parts, and each division is called a *degree Fahrenheit*.

The Réaumur Scale.—The freezing point is 0° as on the Centigrade, and the boiling point is 80° R. The degrees are thus longer than on a Fahrenheit or a Centigrade thermometer of the same size.

6. Conversion of Thermometric Scales.

The interval between the boiling and freezing points, that is, the same temperature difference, is divided into 100 parts on the Centigrade scale and 180 parts on the Fahrenheit, and consequently 100 Centigrade degrees are equal to 180 Fahrenheit degrees, which is the same as saying one degree Centigrade is equal to nine-fifths of a Fahrenheit degree, or one degree Fahrenheit is equal to five-ninths of a degree Centigrade.

100° C. $= 180^\circ$ F.; $\therefore 5^\circ$ C. $= 9^\circ$ F.; $\therefore 1^\circ$ C. $= \frac{9}{5}^\circ$ F., and 1° F. $= \frac{5}{9}^\circ$ C.

In converting Fahrenheit readings into Centigrade degrees, we must subtract 32 (because of what has been said of the freezing point on the former scale) and multiply the number thus obtained by 5 and divide by 9. To change from Centigrade to Fahrenheit, multiply the former reading by 9 and divide by 5 and add 32 to the result.

EXAMPLE.—What temperature on the Fahrenheit scale corresponds to 20° C.?

Answer. 20° C. is 20 C. degs. above temperature of melting ice, *i.e.* $20 \times \frac{9}{5}$ Fahr. degs. above 32° F $= (36 + 32)^\circ$ F. $= 68^\circ$ F.

When it is necessary to refer to temperatures lower than the freezing point of water, a minus sign is placed before the temperature, thus, three degrees below the freezing point of water on the Centigrade scale is written -3° C.

(a) Using this information, make the necessary calculations and fill up the following spaces:

85° C. correspond to	- -	......° F.
50° C.	" - - -	......° F.
26° C.	" - - -	......° F.
10° C.	" " - -	......° F.
4° C.	" " - -	......° F.
-5° C.	" " - - -	......° F.

Also fill up the following blanks:

200° F. correspond to	- -	......° C.
180° F.	" " - - -	......° C.
100° F.	" " - -	......° C.
75° F.	" " - - -	......° C.
40° F.	" " - -	......° C.
10° F.	" " - -	......° C.

7. Graduation of an Alcohol Thermometer.

The alcohol thermometer you have constructed may be graduated by comparison with a Centigrade thermometer. One way of doing this is to stick a strip of blank paper on the tube by means of gum, or you may cover the tube with paraffin wax. Place the thermometer in a funnel containing shavings of ice and make a mark on the paper, or wax, level with the top of the alcohol in the tube. Then plunge both the Centigrade thermometer and the one you wish to graduate into cold water in a beaker. Warm the water and watch the thermometer. Make marks on the paper where the coloured liquid stands as the thermometer reads 10°, 20°, 30°, . . . and number these marks in the same way on the paper or wax, 10°, 20°, 30°. . . . Transfer these marks to the tube itself with a three-cornered file, or fix the thermometer upon a strip of wood having paper glued upon one face, and make the degree marks upon the paper.

8. Graphic Representation of Thermometer Readings

Read your thermometer at a fixed time every day, and plot the observations from day to day on a chart, as you have learnt to do with barometer readings. The degrees can be written

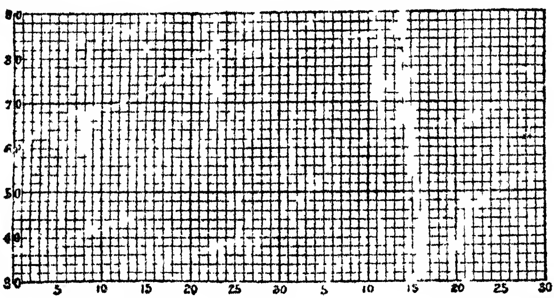


Fig. 8 —Form for recording daily temperature observations

at the ends of the horizontal lines of squared paper, and the days of the month can be written at the top or bottom of the vertical lines as in Fig. 8

9. Effects of Salts in Altering the Freezing and Boiling Points of Water

Freezing Point

(*a*) Place a few shavings of ice or pieces about the size of a pea in a funnel, supported as in Fig. 5, or a beaker sprinkle the ice with salt, then add some more ice, and sprinkle again with salt. Repeat this operation several times, making the proportions of the two substances about 1 part of salt to parts of ice, and then stand in the mixture a thermometer graduated below the freezing point of water. The temperature of the mixture will be found to be below 0° Centigrade. Record the lowest temperature reached.

(*b*) Put a thin test tube, containing a little water, into a mixture of ice and salt. Stand the thermometer in the water, and observe that the temperature never sinks below 0° Centigrade or 32° Fahrenheit while the water remains liquid. You should not, however, leave the thermometer in the water. If you continue the experiment long enough, the water will freeze, and the ice formed will cool down towards the temperature of the freezing mixture of ice and salt.

(*c*) Put some salt water into the test tube instead of fresh water, and stand the test-tube in a mixture of ice and salt. You will find that the water can be cooled below 0° C. without turning into ice.

(*d*) Find the temperature produced when crystallised calcium chloride is mixed with ice.

(*e*) Mix two parts by mass of ammonium nitrate with one part of ammonium chloride, and dissolve the mixture in cold water. Observe the temperature before and after putting the salts in the water.

In every case where salts are present in solution, the freezing point of water is lowered. Pure ice ought, therefore, to be used in determining the freezing point of a thermometer.

Boiling Point.

(*f*) Add a little salt to water. Put the salt water in a test-tube or flask, fitted as in Fig. 6, and, using a thermometer graduated above the boiling point of water, find the temperature, (i.) of the steam from the boiling salt solution, (ii.) of the boiling liquid itself. Record your results. Compare with Exercise 4 (*a*). Why was the thermometer held in the steam? Repeat the exercise, using calcium chloride instead of salt.

10. Determination of Melting Point.

(*a*) Draw out, in a blow-pipe flame, a piece of glass tubing so as to make a small thin-walled tube, about 2 or 3 inches long and about ·1 inch in diameter. In this put some finely powdered sulphur and fix the tube to the bulb of the thermometer (it will

probabl . . . . . if moistened; if not, it may be secured with a platinum or an india-rubber ring). (Fig. 9.) Place the thermometer bulb with the lower part of the tube in a beaker of sulphuric acid or glycerine with the sealed end of the tube and the bottom of the thermometer at the same distance above the bottom of the beaker. Heat *gently* with a small flame. The sulphuric acid is kept at a uniform temperature by raising and lowering the curved stirring rod shown in the figure. Watch the sulphur carefully, and directly you see it to be melting note the temperature recorded by the thermometer, that is, the melting point of the sulphur.

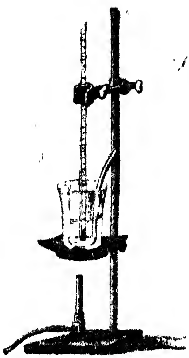


FIG. 9.—Determination of melting point.

Melting point of sulphur, - ......° C.

(*b*) Similarly find the melting point of bee's-wax. Cut off a length of the small thin-walled tube and dip it into some melted wax. In this way the fine tube becomes filled with wax which soon solidifies. Proceed as before.

Melting point of bee's-wax, - ......° C.

(*c*) Melt a little paraffin wax in a beaker, and immerse the bulb of a thermometer in the liquid. When the thermometer is taken out, a thin film of liquid paraffin will be seen upon it. Let the bulb cool, and notice the temperature when the wax assumes a frosted appearance, indicating that it is solidifying. When the wax on the bulb has became solid place the thermometer in a beaker of water and gently heat the water. Observe the temperature at which the wax becomes transparent again. The mean of this result and the preceding one is the melting point of paraffin wax.

11. Determination of Boiling Points.

(*a*) Put a little methylated spirit in a test-tube, and gradually heat it in a beaker of water until it boils. Find the temperature of the boiling spirit and of the vapour, and record the results.

(*b*) A convenient arrangement for determining the boiling point of a liquid is shown in Fig. 10. The vapour passes up into the bulbs and out of the side tube, its temperature being shown by a thermometer, the bulb of which is adjusted just below this outlet. If available, use this apparatus to determine

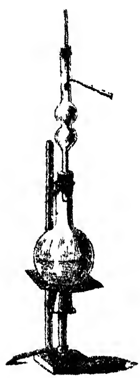


Fig. 10. Flask fitted with tube for the determination of boiling point

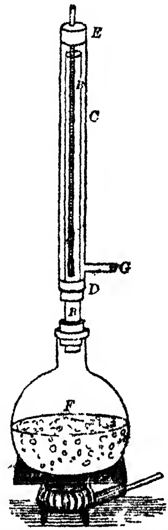


Fig. 11. Apparatus for the accurate determination of boiling points

the boiling points of water, turpentine, milk, beer, vinegar, and whisky, or of as many of these liquids as you can obtain.

On account of the condensation of vapour upon the thermometer, the method used in the preceding exercises to determine boiling points is not a very accurate one. More exact determinations of the boiling point can be made by means of the apparatus shown in Fig. 11. A can or flask *F* is fitted with a cork, through which a glass or brass tube *B* passes. Surrounding this tube is a wider tube *C*, fitted upon the inner tube by means of a piece of thick india-rubber

tubing *D*. At the top of the outer tube is a cork *E* having a hole in which a thermometer can be fitted. When the water in the flask is boiled, steam passes up the inner tube *B*, and down the wide tube *C*, and escapes at the outlet *G* into the open air.

(*c*) To use the apparatus, gently push the top of the stem of the thermometer into the cork which fits in the outer tube, adjusting it so that the 100° point is just below the cork. Fit the cork in its place, boil the water, and when steam has been coming off for about a quarter of an hour, raise the cork and read the thermometer. Repeat the observation after a few minutes, and when two readings obtained at an interval of about ten minutes agree, record the observation. The temperature you observe is the boiling point of water under the particular conditions existing at the time and place of the experiment.

12. Anomalous Expansion of Water.

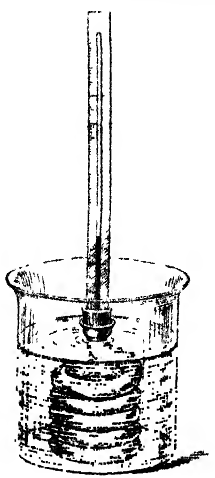


FIG. 12.—Apparatus for the determination of the changes of volume of water near the freezing point.

(*a*) Make a coil of lead or "compo" tubing. Fit an india-rubber stopper, or a good cork, having a glass tube of narrow bore through it, into one end of the coil. Suck boiled water into the coil until it can be seen in the glass tube above the stopper, and then fit a good stopper into the other end of the coil (Fig. 12). Fasten a scale to the glass tube, and then place the coil with the tube and scale into a beaker of water at the temperature of the room, and hang a thermometer in the water.

Notice the position of the surface of the water in the tube, and the temperature of the water in the beaker. Add shavings of ice, or pounded ice, to the water, and when the temperature is steady again notice the position of the top of the water. Continue the

cooling with ice, making observations of the position of the surface for about every three degrees down to 1° C. Then let the water in the beaker gradually rise in temperature, adding a little warm water, if necessary, and again observe the positions at the same temperatures as before. The mean of the two positions observed for each temperature should be taken as the true reading for that particular temperature. Construct a curve like that shown in Fig. 13 to represent your observations of the changes of volume of water at temperatures near the freezing point.

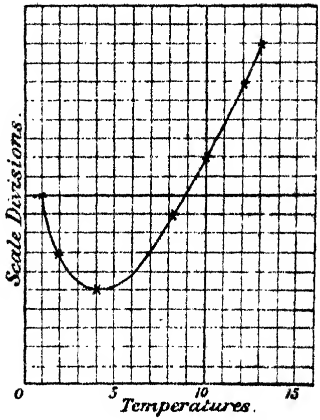


FIG. 13.—Graphic representation of changes in volume of water near the freezing point.

At what temperature has the water in the coil the least volume, and therefore the maximum density?

The changes in volume of water, when cooled down to freezing point, can also be observed by means of a test-tube of water having a good stopper, with a narrow glass tube in it instead of the coil used in the preceding exercise. But as the expansion of water between 4° C. and 0° C. is very small, the experiment has to be carefully performed to be successful.

13. Density of Water and Ice.

(*a*) Half fill a burette or graduated glass tube with paraffin oil. Put the burette in a jar containing ice and water until the temperature reaches 0° C. Observe the level of the paraffin oil in the burette. Gently drop in pieces of dry ice, and observe the volume of the ice added by noticing the rise of level of the oil. Let the ice melt, and when it is converted into water, again observe the reading of the burette. This reading will give you

the volume of water produced by the melting of a certain known volume of ice. Find the ratio of the volume of the water produced to that of the ice from which it came. Hence the result will give you the density of ice.

(*b*) Fill a small narrow-necked bottle with water, and cork it up tightly. (A bulb blown at the end of a glass tube is better.) Place the bottle in a bowl and cover it with a freezing mixture of ice and salt. Carefully cover the bowl with a duster or cloth until you hear the bulb burst, then take off the covering and examine what has happened. Describe and explain the result of your experiment.

Try to explain, from what you have learnt by your experiments, why water pipes burst in winter. How is it that the burst pipes are not found until the thaw sets in?

(*c*) Put a few pieces of ice in a glass of water. Does the ice float or sink? Is ice heavier or lighter than an equal bulk of water? How do you account for the difference of density between ice and water?

(*d*) Cut a piece of wax candle into chips, and put them into a test tube. Melt the wax by gently heating the test tube, and while it is liquid throw in a few more small pieces. Do these pieces float or sink? Can you tell from your observations whether wax contracts or expands when passing from the liquid to the solid state?

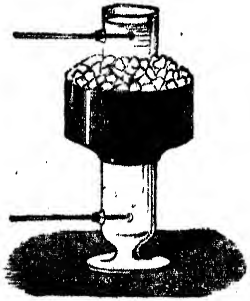


FIG. 14.—Hope's apparatus for the determination of the temperature of maximum density of water.

14. Maximum Density of Water.

When water contracts its density must increase, and the degree at which contraction ceases and expansion commences marks therefore the point of *maximum density of water*. The changes of density near the freezing point can be indirectly observed by means of Hope's apparatus (Fig. 14),

the principle of which is based upon the fact that the denser parts of a liquid sink and the lighter rise to the top. The apparatus consists of a glass or metal vessel having a trough surrounding the middle part. Two thermometers are inserted in holes near the top and bottom of the instrument respectively.

(*a*) To use the apparatus, fill the inner cylinder with cold water—at a temperature of 6° C. to 8° C.—and the trough with a freezing mixture. Notice the readings of the thermometer at intervals of a minute or two, and record as below.

TIME.	TOP THERMOMETER.	BOTTOM THERMOMETER.

At first the bottom thermometer will be most affected, while the top one remains at nearly the same degree. When the temperature of 4° C. is reached, the bottom thermometer ceases to fall, but the upper one commences to fall rapidly, and continues to go down until a temperature of 0° C. is reached if the experiment is continued long enough.

Explain the changes observed by means of the facts you have learnt, as to the variations of the density of water with temperature.

The apparatus for performing this experiment can easily be made in a workshop. Holes are cut in the side of a tin canister, and short tin tubes are soldered into them. Corks for holding the thermometers are fitted into the tubes. For the trough a large tin canister is obtained and reduced to a convenient height. A hole is then cut in the bottom to permit the trough to fit upon the outside of the smaller canister. This must, of course, be done

before the top tube is soldered on. To obtain the best results with this or any other form of Hope's apparatus, the cylinder should be wrapped in cotton wool and stand on similar material; and the observer should only stand near it when he wishes to read the thermometer.

CHAPTER II.

CONDUCTION AND RADIATION OF HEAT.

15. Relative Conductivities of Metals.

(*a*) Twist an iron and a copper wire, about 10 cm. long, at one end, and put the twisted end in a small flame. After a short time the wires become too hot to hold. Why? Which wire reaches this stage first?

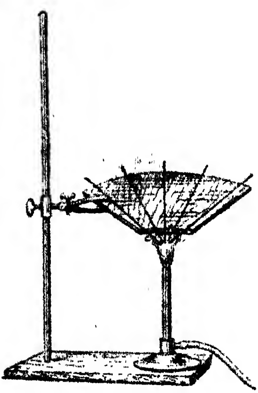


FIG. 15.—Experiment to show difference of conductivity of heat along metal rods.

(*b*) Obtain wires of copper, iron, brass, German silver, and of any other metals available. Let the diameters be as nearly equal as possible, and the lengths about 15-20 cms. Fasten the wires upon a strip of wood as shown in Fig. 15). Support the wood in a horizontal position and heat the wires with a flame where they meet. After a few minutes slowly move a safety match along each wire in succession, commencing at the ends away from the flame, and notice the points at which the matches will light. Repeat the experiment several times; then take away the flame and measure the distance of these points from the heated ends. Find the average distance for each wire.

The numbers obtained will show roughly the relative conducting powers of the metals of which the wires are composed. Write down the names of these metals in the order of their ability to conduct heat, beginning with the best conductor, and putting against each name the average distance at which the match was ignited upon it.

(*c*) With the small cylinders of metal provided and your steel scale (if not too heavy) perform the following experiment. Fix the scale upon one of the cylinders of metal by means of a small lump of bees'-wax. Place the cylinder on a warmed plate of iron, supported on a tripod as shown in Fig. 16. Heat is conducted by the cylinder to the wax, which eventually melts, causing the scale to fall over. Repeat the experiment with the different cylinders and note the number of seconds taken for the wax to melt.

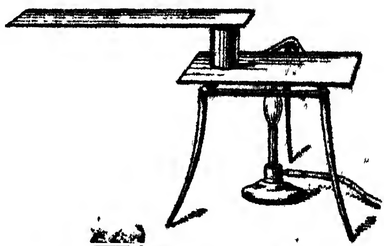


FIG. 16.—A conductivity experiment.

	No. of seconds in which wax melts
(*a*) Copper, - - -	......
(*b*) Brass, - - -	......
(*c*) Bismuth, - - -	......
(*d*) Hard wood, - -	......

As some metals take more heat than others to raise them to the same temperature, the results obtained will not accurately show the difference of conducting power of the cylinders used.

(*d*) Bore a number of holes in a cork bung of such a size that several rods of different material but the same length and thickness just fit. Push these rods through the cork so that they all

protude equally. Cover the longer parts with wax by means of a brush or cloth dipped in melted wax. Now put the cork bung on to the top of a tin canister or beaker in which water is being boiled in such a way that the shorter unwaxed parts of the rods dip into the water. Notice that the wax melts further along some rods than others. Allow the rods to remain until no further melting is observed, and then measure each rod from the extremity to the beginning of the unmelted wax. The conductivities of the metals are proportional to the squares of the distances along which the wax is melted.

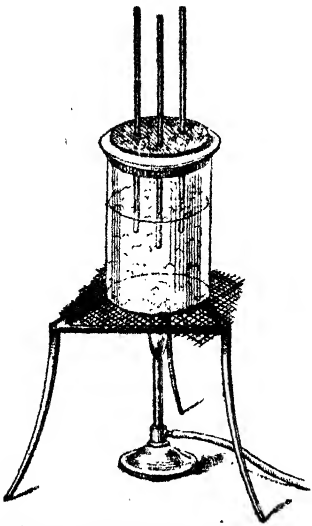


FIG. 17.—Rods heated by hot water to show difference of conductivity.

The following effective arrangement for determining the relative thermal conductivities of metals has been devised by Mr. Edwin Edser.[1]

(*e*) Procure a piece of brass tube, about 10 cms. in diameter and 20 cms. in length. Close one end by means of a brass disc. Bore a number of holes in this disc to receive the extremities of rods of copper, brass, iron, etc., each rod being 2·5 mm. in diameter and about 15 to 20 cms. in length. Solder the rods in position perpendicular to the disc.

Upon each rod place a small index, made from a piece of copper wire of about ·8 mm. diameter, bent into the form shown in Fig. 18, a

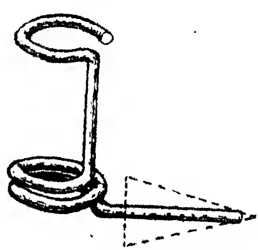


FIG. 18.—Enlarged view of index of Edser's conductivity apparatus.

[1] *Nature*, July 13, 1899.

small arrow-head of blackened paper or mica being attached by shellac varnish. The rings forming part of each index should be wound on a rod *very slightly* larger in diameter than the experimental rods.

To perform an experiment, invert the brass vessel; slip an index on each rod, the single ring (Fig. 18) being left in contact with the disc, and melt a very small amount of paraffin wax round the rings. Support the vessel with the rods downwards, as in Fig. 19. The solid wax will hold the indexes in position. Now pour boiling water into the brass vessel.

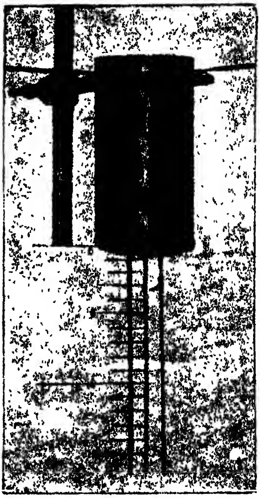


FIG. 19.—Edser's apparatus for demonstrating the relative thermal conductivities of metal. (The left-hand rod is of copper, the middle one of brass, and the right-hand one of soft steel.)

When that part of a metal rod, in the neighbourhood of the double ring of the index, reaches the melting temperature of the wax, the index commences to slip downwards, carrying the wax with it, and when the temperatures of the rods have acquired steady values, the indexes will have descended to points on the various rods where the wax just solidifies, and which, therefore, possess equal temperatures. The conductivities of the rods are proportional to the squares of the distances from the bottom of the brass vessel to the respective positions indicated by the several arrow-heads.

Observe the positions of the indexes on the rods you use and determine the relative conductivities of the substances of which they are composed.

16. Relative Conductivities of Liquids.

(*a*) Fill a narrow test-tube three-quarters full with cold water, and having weighted a small piece of ice by winding wire round it, or in some other way, drop it into the test-tube. Hold the test-tube near the bottom where the piece of ice is, and warm the top of the water in a Bunsen flame, as shown in Fig. 20. The water at the top can be heated until it boils vigorously and yet the ice is not melted, showing what a bad conductor the water is.

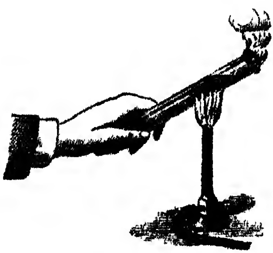


FIG. 20.—Experiment to show that water is a bad conductor of heat.

(*b*) Nearly fill a narrow test-tube with mercury and heat it at the top, as in the preceding exercise. You will find that the test-tube will soon become too hot to hold.

(*c*) Fill the Hope's apparatus, used in Exercise 14 (*a*), or a tin canister similarly fitted with tubes for thermometers, with cold water. Observe the readings of the thermometers. Float the cover of a tin canister upon the top of the water, and pour a little benzene or methylated spirit into it. Ignite the spirit, and notice that the readings of the thermometers remain practically unaltered, and that even the top one is not affected until the spirit has been burning for some time.

17. Radiation and Absorption.

(*a*) Obtain two small bright tin cans or canisters, and fit into each a cork having a hole through which a thermometer will pass. Cover the outside of one of the vessels with lampblack by holding it over a candle or luminous gas flame, or over burning camphor. Put the same quantity of hot water at the same temperature in each, and then cork up the vessels, each cork having a thermometer through it so that the bulb is well immersed in the water. Observe the temperature of each

vessel of water, and if one is higher than the other, cool the vessel until the temperatures are equal. Then put the vessels in a cool place where there are no draughts, and after 20-30 minutes again read the temperatures.

The blackened vessel will be found to have lost or radiated more heat than the bright one.

(*b*) Similarly equally fill a blackened and a bright vessel with cold water of the same temperature, and hang them for 20-30 minutes at the same distance above an iron plate, supported on a tripod stand and heated by a laboratory burner. At the end of this time observe their temperatures.

The blackened vessel will be found at a higher temperature than the bright one, therefore a lamp-black surface absorbs heat better than a bright metallic surface.

18. Construction of a Differential Air-Thermometer.

(*a*) Fasten two flasks or bulbs together with air-tight joints, by a tube bent six times at right angles. Before fixing this tube in position put in some coloured liquid, so that it fills the bend as in Fig. 21.

Notice that whenever one bulb is at a higher temperature than the other the level of the liquid in the parallel tubes is altered, the liquid approaching the bulb with the lower temperature.

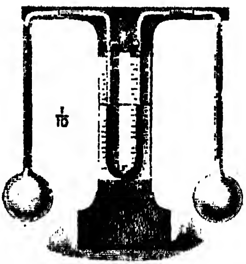


Fig. 21.—A differential thermometer.

19. Emissive and Absorptive Powers of Different Surfaces.

(*a*) Cover one bulb of a differential thermometer with lamp-black, and the other with tinfoil. Place the thermometer so that the bulbs are at equal distances from a vessel containing

hot water. Notice and explain the movement of the liquid in the thermometer.

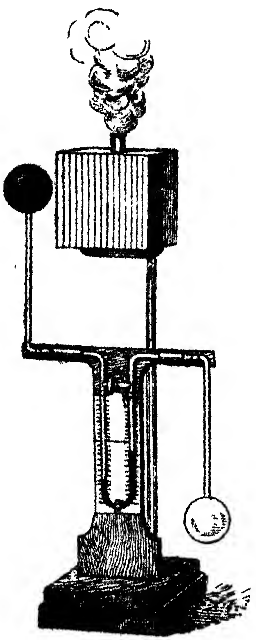


FIG. 22.—Differential thermometer arranged for radiation experiments.

(*b*) Blacken one of the bulbs of a differential thermometer. Turn up this bulb into the position shown in Fig. 22. Obtain a small square biscuit box or vaseline tin. Cover one of the vertical faces with lamp-black, upon another paste a piece of white paper, and roughen another by rubbing it with coarse emery cloth. Fill the box with hot water, and support it on a retort stand near the upper bulb of the differential thermometer, beginning with the bright unaltered side facing the bulb. Observe the depression of the liquid in one of the parallel tubes of the thermometer. Turn all the faces successively towards the upper bulb, taking care that the distance is the same in each case, and observe the effect produced.

Which of the faces radiates most heat? Write down the names of the surfaces in the order of their radiating power, as indicated by your observations.

20. Rate of Cooling.

(*a*) Obtain a small tin canister, place it in a large beaker of water, and put enough shot in it to sink it until the top is a little higher than the top of the beaker, when the water-level outside is about that indicated in Fig. 23. Observe and record the temperature of the water. Bore a hole in a slab of wood and insert a cork, having a hole through which a thermometer will pass,

Hold the thermometer in the hot air rising from a flame until the temperature shown by it is 70° to 80° C. Then, and not before, push the thermometer through the cork—the top of the stem first—and place the wood on the top of the beaker, so that the bottom part of the thermometer is enclosed in the tin vessel. Observe the temperature every half-minute as the thermometer cools, until its temperature has fallen within about 10° of that of the water. Record the observations as indicated below.

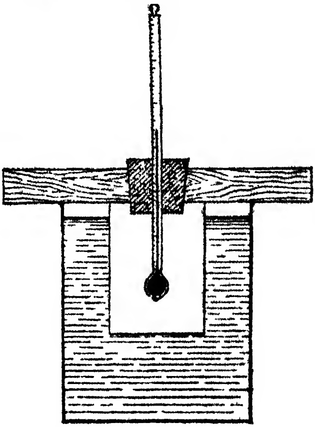


FIG. 23.—Experiment on the rate of cooling.

Temperature of Thermometer	Excess over Temperature of Water	Average Excess	Fall in Degrees per Half Minute	Average Excess / Fall

The average excess is obtained by dividing the sum of two successive numbers in the second column by 2; it is the mean of the excess at the beginning and end of the half-minute.

Newton's law of cooling states that *if an object is enclosed in a chamber of uniform temperature the rate at which it loses heat is proportional to the excess of the temperature of its surface above that of the chamber.* The numbers in the last column ought therefore to be the same if the law were strictly true, but as it only holds good when the excess is small, you will find that the numbers will differ slightly.

CHAPTER III.

MEASUREMENT OF EXPANSION OF SOLIDS, LIQUIDS, AND GASES.

21. Expansion of Solids.

(*a*) Obtain an iron or brass rod of about six inches long, fitting into a gauge cut out of brass (Fig. 24). The rod just fits the gauge when both are at the ordinary temperature. Heat the rod; it will not now go into the gauge, therefore its size has been increased by heating.

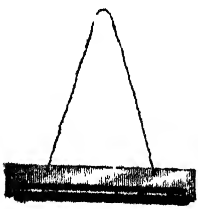


FIG. 24.—Rod and gauge to show expansion by heat.

(*b*) Obtain a metal ball and a tin canister, into which the ball will just fall when cold. Instead of the canister a ring of a retort stand, through which the ball just passes, may be used, or a circular hole of the same diameter as the ball may be cut in a piece of metal. Holding the ball by an attached chain or wire, heat it in a gas

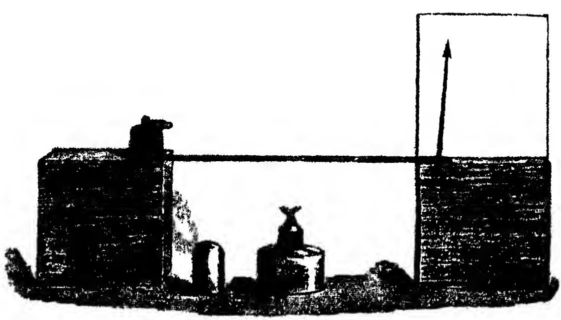


FIG. 25.—Apparatus to show the linear expansion of a metal rod when heated.

flame. It will not now fit the hole through which it would pass when cold. Why is this?

(*c*) Obtain a metal bar about a foot long—the rod of a retort stand will do. Take two blocks of wood and lay the rod between them, as shown in Fig. 25. Place a heavy weight on one end of the bar, or fix it down tightly by cutting a strip of flexible metal, and nailing it over the bar in the form of a clamp. Under the other end put a fine needle, with a straw on it, as shown in the figure. Heat the bar with a flame, and notice that the pointer moves, on account of the expansion of the bar.

(*d*) Make or obtain a compound strip made of two metals, riveted together. A strip of copper, 15 cm. long and 2 cm. wide, fastened to a strip of iron of the same size is a convenient form; or a strip of ebonite may be glued to a strip of pine of the same size and thickness. Heat the compound strip and observe that it bends into a curved form on account of the unequal expansion of the two materials. Which of the strips expands by the greater amount?

22. Coefficient of Linear Expansion.

(*a*) To obtain a measurement of the linear expansion of a rod when heated to a known temperature, the form of apparatus[1] shown in Fig. 26 may be used.

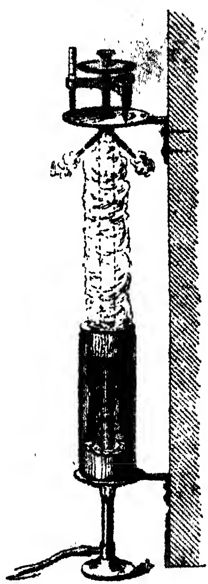


Fig. 26.—Apparatus for determining the linear expansion of a metal tube.

To a tin can, as long as can be obtained, fit a cork, and through this pass a tube of copper or of other metal about 3 ft. long, closed above by a flat top. Near the lower end of the tube drill four or five holes about $\frac{1}{4}$ inch in diameter, and near the top drill one or two holes fitting to them short pieces of copper or brass tube. Measure the length of the tube at the temperature of the air. Place a Fletcher burner near a wall or wooden upright, and place on the burner or other support the tin can with the copper tube, holding it by a clamp. Let the

[1] In use at St. Dunstan's College, Catford.

lower end of the tube rest upon the bottom of the can (Fig. 26). At about the level of the top of the copper tube pin a bracket of iron, and drill a hole which is just above the top of the copper tube.

To measure the expansion, wrap the exposed part of the copper tube with cotton wool, and place on the bracket a sphero-meter, and adjust so that the screw just touches the top of the copper. (It is of course not advisable to use a good sphero-meter for the experiment, as some steam may condense upon it.) Take the reading, and screw up the spherometer. Boil the water in the can, and when steam has been issuing for some time again screw down the spherometer and take the reading. Through what distance has the top of the copper tube moved? Then calculate thus:

A length of ...... cm of copper when raised .. .. degrees expanded .. ... cm.

Therefore 1 cm of copper when raised 1 degree expands ...... cm.

The value so obtained is the coefficient of expansion of the metal used

23 Expansion of Liquids.

(*a*) Close one end of a glass tube about 30 cm. long and 3 mm. bore Partly fill the tube with water, and fasten it to a thermometer by means of threads or india rubber bands Place the combination in melting ice, so that the water is surrounded by the ice, and observe the degree on the thermometer level with the surface of the water in the tube. Repeat the operation with the combination successively in water at 50°, 60°, 70°, 80°, and 90°, taking care that the water in the tube is completely immersed Now take the combination out of water, and measure the distance from the bottom of the tube to the point at which the surface of the water stood in each case, taking care that the tube does not move. Record the observations thus:

Temperature.	Length of Water Column.	Increase of Temperature	Increase of Length.

Find from these results, the average increase of length for 1° rise of temperature, and the fraction which this increase is of the original length.

As the tube is uniform in bore the lengths of the column of water are proportional to the volume of the water, so that your results will show you the increase of the volume of water for a rise of temperature of 1°, expressed as a fraction of the original volume.

(*b*) Repeat the preceding exercise, using turpentine, alcohol, or mercury instead of water in the tube, and find in the same way the fraction of its volume at 0° by which the liquid expands for a rise of temperature of 1° C.

24. Real and Apparent Expansion of Liquids.

Hitherto the expansion of the glass containing a liquid has not been considered. But the glass, like most substances, also expands when heated, though it may not be noticed, as the expansion of the liquid is so much more. To convince yourself that the glass vessel in which the liquid is contained really expands, proceed as follows:

(*a*) Procure a 4 oz. flask and fit it with a cork. Bore a hole through the cork and pass through a long glass tube which fits tightly. *Fill* the flask with cold water coloured with red ink. Push the cork into the neck of the flask and so cause the coloured water to rise up the tube. See that there is no air between the cork and the water. Now plunge the flask in hot water, and notice that first of all the liquid in the tube falls. Why? Then it rises up the tube, that is, the volume increases.

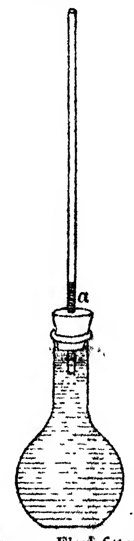


FIG. 27.—Flask fitted with tube, to show real and apparent expansion of a liquid.

That fraction of its volume at 0° C. which a body expands on being heated through 1° C. is called its *coefficient of cubical expansion.*

The amount which a liquid expands appears less than it actually is because of the expansion of the vessel. This expansion which it appears to possess is called its *apparent expansion.* To obtain the real expansion we should have to add to the apparent expansion the amount the glass expands, or,

$$\text{real expansion of a liquid} = \text{its apparent expansion} + \text{expansion of the glass.}$$

If any two of these values are known, the third can evidently be easily calculated. The following exercise shows this.

25. Weight Thermometer or Dilatometer.

Knowing the absolute expansion of mercury (= ·000181) find the expansion of glass by means of a density bottle or weight thermometer as follows.

(*a*) Determine the mass of your density bottle by weighing. Fill it with mercury, and, handling as little as possible, place it in a tray and insert the stopper. Again weigh, and by subtraction determine the mass of mercury which just fills the bottle at the temperature of the room. Support the bottle full of mercury in a cage made of wire gauze to which wires are attached to hang the bottle and cage from a clamp of a retort stand (Fig. 28). Lower the cage into a vessel of water so that the top of the stopper of the bottle

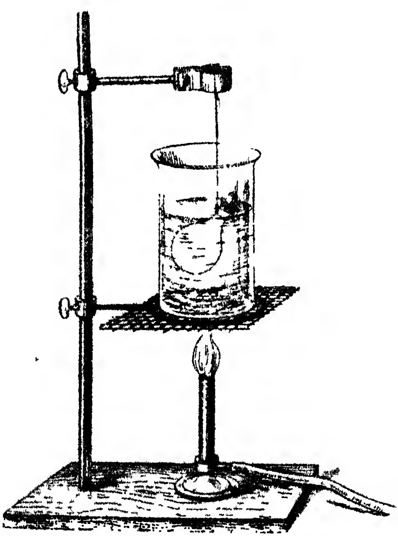


FIG. 28.—Determination of the expansion of the glass of a density bottle by the dilatometer method.

is just out of water. Arrange a mercury themometer by the side of the bottle. Gradually warm the water. Notice the expansion of the mercury through the hole in the stopper. When the water is at 70° C., quickly lift the cage out of the water, and at the same moment, with a clean piece of paper, push off the drop of mercury on the top of the stopper. The bottle is just full of mercury at 70 C. Place the bottle on one side to cool. Again weigh, and, by subtraction, determine the mass of mercury which just fills the bottle at 70° C. Record your results:

Temperature of room, - - -	...... t° C.
Mass of density bottle, - - -	...... gms.
Mass of bottle when full of mercury at temp. of room, - - - -	...... gms.
Mass of mercury which fills bottle at temp. of room, - - -	... $= W$ gms.
Temperature to which bottle is heated,	...... $= T$° C.
Mass of mercury and bottle after escape of mercury as it is heated to T° C., - - - - - -	..... gms.
Mass of mercury which just fills bottle, at T° C - - - - - -	......$= w$ gms.

Proceeed to consider the experiment as follows. Since w grams of mercury just fill the bottle at T° C., it is evident that in heating the bottle from t° C. to T° C., $W - w$ grams of mercury have escaped. The density of mercury at t° C is, let us say, d. Then the W gms. occupied $\frac{W}{d}$ c.c. At T° C., w gms. occupied the *same volume* (neglecting the glass expansion) but if *cooled down to* t° they would only occupy $\frac{w}{d}$ c.c.; therefore, $\frac{w}{d}$ c.c. at t° would, if raised to T°, expand to $\frac{W}{d}$ c.c. The coefficient of expansion is

$$\frac{\frac{W}{d} - \frac{w}{d}}{\frac{w}{d}} \cdot \frac{1}{T - t}, \text{ that is, } \frac{W - w}{w} \cdot \frac{1}{T - t}.$$

But the real expansion of mercury = 0·000181.

And it has been seen (p. 28) that

Expansion of glass = real expansion − apparent expansion.

(*b*) Check your result by putting the density bottle into water again and raising the temperature to 90° C. Repeat the weighing and calculation.

Instead of a density bottle, a U-tube of the form shown in Fig. 29 may be used. One end of the U-tube is drawn

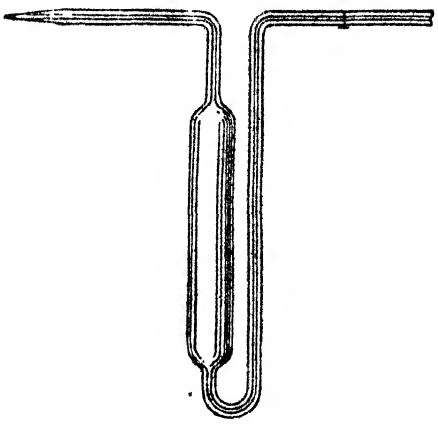


FIG. 29. - A convenient form of dilatometer.

out to a fine point. The vessel can easily be filled with the liquid to be used by applying suction at the other end while the pointed end dips into the liquid. The most convenient form of vessel to use is a U-tube having a stop-cock at one end; for the stop-cock can be turned off when the vessel is being heated, so that the liquid can only escape at the other end. This form, however, is not essential. Any vessel of this kind, which provides a means of estimating temperature by the use of the balance, is known as a weight thermometer or dilatometer.

26. Coefficient of Expansion of a Liquid.

The coefficient of expansion of a liquid, *e.g.* alcohol, can be obtained by means of a density bottle or weight thermometer, used in the same way as in the preceding exercise.

(*a*) Determine the mass of a density bottle or weight thermometer of other form. Fill the vessel with alcohol and find the mass of the liquid. Observe the temperature of the alcohol. Now, place the vessel in water and heat the water to a temperature of 40° C., keeping it at that temperature for 10 or 15 minutes. Then take out the vessel, and, when it is cool, find its mass. Your weighings will give you the mass (W) of a certain volume of alcohol at the temperature (t) of the room, and the mass (w) at the temperature (T), viz., 40° C. Record your observations as in the preceding exercise.

If the mass of the weight thermometer alone is represented by m, the mean coefficient of expansion of the alcohol between the two temperatures t and T can be found by the equation:

$$\text{Coefficient of expansion} = \frac{W - w}{(W - m)(T - t)}.$$

(*b*) Find by the method used in the preceding exercise the coefficient of expansion of turpentine.

If the coefficient of cubical expansion of glass is given, the real expansion of a liquid can be determined by means of a weight thermometer. In this case you proceed exactly as in the last two experiments. In calculating you first obtain the apparent expansion of the liquid as in the preceding exercise and afterwards add the cubical expansion of glass; the sum will give the real or absolute expansion of the liquid.

27. Coefficient of Expansion of a Gas.

(*a*) Obtain an 8-oz. flask fitted with a cork and a narrow glass tube about ten inches long. Remove the cork and tube, and, by suction, draw a little red ink into the end of the tube near

the cork. Re-insert the cork and warm the flask. Notice that the air in the flask gets larger and pushes the red ink along the

(*b*) Obtain a piece of thermometer tubing of about 1 mm. bore and 20 cm. long. Suck into it a length of about 1 cm. of mercury. Seal one end of the tube and arrange that the index of mercury comes near the middle of the tube when the end has been closed and the tube is cool. Fasten the tube to a thermometer, closed end downwards, as in Exercise 23 (*a*). You have in it a certain volume of air, and can find the volume at different temperatures as you did with liquids. Place the combined thermometer and tube in melting ice and notice the position of the air column with reference to the thermometer scale. Repeat the operation for every 10° up to 100° C., taking care that the air column is completely immersed in each case, and giving the tube two or three taps before making an observation, in order to make sure that the mercury is not sticking to the tube. Record your observations thus:

TEMPERATURE.	LENGTH OF AIR COLUMN.	EXPANSION FOR 10° C.	AVERAGE EXPANSION FOR 1° C.

As the tube is cylindrical and uniform in bore, the volume of the air in it is proportional to the lengths of the air column. The average increase of volume for 1° C., expressed as a fraction of the volume at 0° C., is the *coefficient of expansion*. Find from your results the coefficient of expansion of air.

When a gas is heated in circumstances where, as in these experiments, free expansion is possible, it is said to expand *under a constant pressure*. Both at the beginning of the experiment and after the gas has been heated, the pressure to which it is subjected is simply that of the atmosphere.

(*c*) Fit up the apparatus shown in Fig. 30, which shows an 8-oz. flask fitted with an india-rubber stopper containing a single hole, through which passes a glass tube bent twice at right angles. To the end of the glass tube outside the flask is fixed a strong piece of india-rubber tubing, and into its other end a thistle funnel is pushed. Make a mark on the right-angled tube. Pour mercury into the funnel until it reaches the mark. Now plunge the flask into warm water, and observe that, as before, the air expands and depresses the mercury below the mark. Raise the funnel until the mercury is again brought to the mark. Notice that now there is a length *b* more mercury in the tube of the funnel and, as you have previously learnt, this difference in the mercury level in the two tubes represents an increase in pressure of the gas in the flask. Also notice that the heated gas has the same volume as at first.

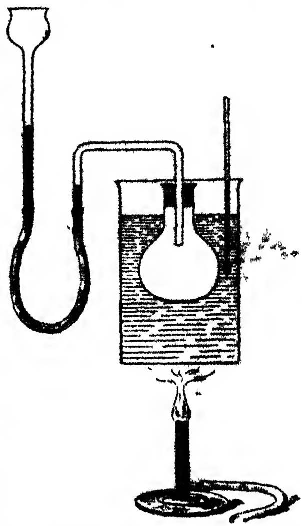


FIG. 30.—Apparatus for observing increase of pressure of a gas heated at a constant volume.

The result of heating a gas which is not allowed to expand is to increase the pressure which it exerts on the sides of the containing vessel. Under such conditions, it is said to be heated at a *constant volume*, and the effect of heating is to cause an increase in pressure. The pressure of the gas at the end of the last experiment is evidently equal to the pressure of the atmosphere together with that represented by the column of mercury *b*.

[illegible] The Coefficient of [illegible] Air heated under a constant [illegible]

(a) Carefully d[illegible] about 400 c.c. capacity, and fit it with an india-ru[illegible] one hole. Make a plug by rounding off i[illegible] blowpipe flame a short length of glass rod, which just [illegible] the hole in the stopper. Place the stopper [illegible] flask so that it fits tightly, and with a [illegible] diamond is better), make a mark round [illegible] the flask at the bottom edge of the stopper. Plunge the flask into a bath[1] of boiling water and fix it in position by a [illegible]. Leave the flask exposed to the boiling water and steam at least a minute, and then close the flask by firmly inserting the plug. Find the temperature of the water (T° C.) Remove the flask and place it, stopper downwards, in cold water in a pneumatic trough. Take out the plug, and observe that water enters the flask. Depress the flask until the water within and without it is the same, and re-insert the plug. Record the temperature (t° C.) of the cold water. Measure the volume (v) of the water in the flask by means of a cubic centimetre jar. Fill the flask up to the mark with water from the pneumatic trough, this gives the volume (V) of the air in the flask at the temperature of the air.

Proceed to calculate the coefficient of expansion as follows:

The volume of air at the temp. of cold water which fills the flask up to the mark when it is at a temp. T° C. $= V - v$.

This volume of air on being heated from t° to T° C. expands an amount represented by v.

$\therefore$ Apparent coefficient of expansion of air for 1° C.

$$= \frac{v}{(V-v)(T-t)}.$$

The real expansion is, as in the case of a liquid, got by

[1] The tin boxes in which caustic soda is supplied answer very well (Adamson).

adding the cubical coefficient expansion of glass, but as compared with that of air this is very small; the correction to be made is not large.

(*b*) Instead of using a large flask, a test-tube having a one-holed india-rubber stopper, which can be plugged with a piece of glass rod, may be employed. Weigh the test-tube thus fitted and then place it in a flask containing water, and of such a size that the rim of the test-tube rests on the top of the neck of the flask. Record the temperature of the air in the test tube. Boil the water in the flask, and after it has been boiling for a few minutes insert the plug in the stopper of the test-tube. Remove the test-tube and hold it under water. Remove the plug; water rushes in. Hold the test-tube, stopper downwards, so that the level of water is the same inside and outside; then replace the plug, lift the tube out of the water, dry it and weigh it. Weigh it again full of water. Subtract the mass of the test-tube and fittings from each result so as to obtain the mass of water in each case. You can then deduce the volume of air in the test-tube at the temperature of cold water and at the temperature of boiling water, and can therefore determine the coefficient of expansion.

29. Determination of Absolute Zero.

If several experiments are made to determine the expansion of air and other gases at constant pressure it will be found that the expansion is uniform, every perfect gas expanding $\frac{1}{273}$ of its volume measured at 0° C. for a rise of 1° C.

Deduce the absolute zero of temperature by plotting the results obtained in 28 (*a*) for the expansion of air. Number your squared paper as shown in Fig. 31 or on some other convenient scale. In the illustration, vertical distances equal to the side of a single square represent 10 degrees of temperature on the Centigrade scale, and horizontal distances of an equal length represent 10 c.c. of volume. Mark points *A* and *B* representing the volume at the temperatures of the hot and cold water respectively. Produce the line which joins these points until it cuts

the line of temperatures, which it will do below the origin

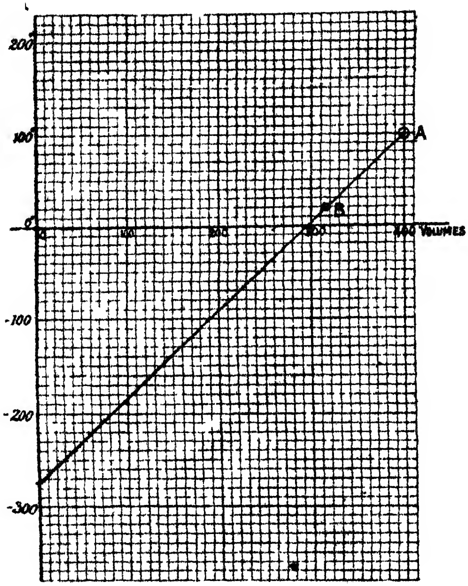


FIG. 31.—Graphic determination of the absolute zero of temperature

at a point representing $-273°$ C, if your observations have been correctly made

30. The Coefficient of Increase of Pressure of Air heated at a constant volume.

(*a*) Fit up the apparatus described in Expt. 27 (*c*) being careful to make the right-angled tube as short as possible, since it is exposed to the air during the experiment, and its temperature is in consequence below that of the hot water in the bath The tube selected must also be a narrow one, so that the change of volume of the air contained by it may be inconsiderable. If it is too narrow, however, there is a great tendency for the column

of mercury to break, and the reading of the height of the mercury column becomes uncertain. Perform Expt. 27 (*c*) again, starting with the highest temperature, and carefully read the difference in height between the top of the mercury column in the funnel tube and the mark previously made on the other tube for several temperatures of the water in the bath.

Place the flask in melting ice and again record the position of the mercury in the funnel tube when that in the other tube is at the mark.

Record your results as follows:

Temperature of Bath.	Height (cm.) of Barometer.	Height (cm.) of Mercury in the Funnel Tube above or below the Mark.	Total Pressure in Cm. of Mercury.

Calculate the coefficient of increase of pressure as follows:

The fall of temperature is from ......° C. to ......° C. $=\theta°$ (say).

" " total pressure " ......mm. to ......mm. $=p$ (say),

∴ increase of pressure for a rise of $\theta°$ C. $=p$;

" " " 1° C. $=\frac{p}{\theta}$

Knowing this, calculate the pressure, which should, if this increase per degree is regular, be observed at 0° C., using one of the observations in your table (preferably one near the temperature of the room). Let the temperature selected be $t°$ C., and the corresponding total pressure be P_t.

$$\therefore \text{ Pressure at } 0° \text{ C.} = P_t - \frac{pt}{\theta} = \ldots\ldots$$

Compare this result with the pressure observed when the flask is in melting ice.

Now, the coefficient of increase of pressure at constant volume

$$= \frac{\text{increase of pressure for } 1° \text{ C.}}{\text{pressure at } 0° \text{ C.}} = \ldots\ldots$$

Find this coefficient, using both the observed and calculated pressure at 0° C.

CHAPTER IV.

SPECIFIC AND LATENT HEATS.

Equal masses of different substances require different quantities of heat to raise their temperatures by equal amounts, and conversely, equal masses of different substances give up different quantities of heat in cooling through equal ranges of temperature.

31. Unit of Heat Quantity.

(*a*) Weigh about 200 gm. of cold water into a beaker, and observe its temperature. Put the same amount of water into another beaker; heat it to about 50° C. Now place the beaker of hot water on your table, with a thermometer in it, and observe its temperature. When the temperature has fallen to say 48° C. take hold of the beaker with a duster, and quickly pour the hot water into the cold. Stir up the mixture with the thermometer, and observe the temperature after mixing. Record your observations as below.

Mass of cold water, - - - - -	......gm.
Temperature ,, - - - - - -	......° C.
,, of mixture, - - - - -	......° C
Number of degrees through which the cold water was raised in temperature, - -	......° C.
Mass of hot water, - - - - - -	......gm.
Temperature of hot water, - - -	......° C.
Number of degrees through which the temperature of the hot water fell, - -	......° C.

Tabulate the gain and loss that occur, as shown below.

GAIN.	LOSS.
Mass of cold water × its rise of temperature	Mass of hot water × its fall of temperature

= .... × .... = ... × ....

Your results will indicate that the gain is slightly less than the loss. This is not really the case, and it only appears so because the amount of heat required to raise the temperature of the glass of the beaker containing the cold water has not been taken into consideration.

The amount of heat required to raise the temperature of one gram of water 1° C., or the amount given out by a gram of water in falling 1° C. in temperature is the unit employed in measurements of heat quantity, and is termed a *calorie*.[1] The number of calories gained or lost when water is heated or cooled is, therefore, obtained by multiplying the mass of the water by the rise or fall of temperature measured in degrees Centigrade.

32. Capacities of Bodies for Heat.

(*a*) Heat equal masses, for instance 100 grams, of lead and water in the same beaker. Provide two other beakers containing equal masses of cold water. Put the hot lead in one of these, the hot water into the other. Stir and note the temperatures.

Mass of hot lead, -	.... gm.	Mass of hot water -	......gm.
Temperature „ -	......° C.	Temperature „ -	......° C.
Mass of cold water, -	....gm.	Mass of cold water, -	......gm.
Temperature „	......° C.	Temperature „ -	......° C.
Temp. of mixture, -	......° C.	Temp. of mixture, -	......° C.
Temp. of cold water raised through -	......° C.	Temp. of cold water raised through -	......° C.

Equal amounts of water at the same temperature are thus shown to be heated to different extents by equal masses of water and lead at the same high temperature.

(*b*) Mix 100 gms. of water at the temperature of the air with 100 gms. of iron at the boiling point of water, and notice the temperature of the mixture.

[1] This unit is sometimes termed a *therm*, or a *gram-calorie*, to distinguish it from the *kilogram-calorie*. In these pages, the word calorie is used as defined above.

Temperature of 100 gms. of water, - - ......° C.
" " " iron, - - ......° C.
" " mixture, - - - - ......° C.

(*c*) Mix 100 gms. of water at the boiling point with 100 gms. of iron at the atmospheric temperature

Temperature of 100 gms. of water, - - ......° C.
" " " iron, - - ......° C.
" " mixture, - - - - ......° C.

The resulting temperature in the latter case is much higher, showing that a given mass of water at a certain high temperature contains much more heat than an equal mass of iron at the same high temperature.

(*d*) Weigh out 50 gms. of cold water, and, as before, observe its temperature. Put into a test-tube an equal mass of

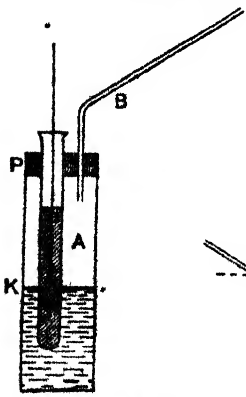


FIG. 32.—Apparatus for heating substances for specific heat experiments. A, test-tube; B, outlet for steam; P, cork; K, can containing water.

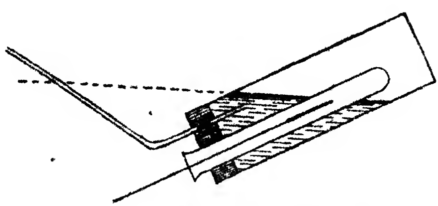


FIG. 33.—Method of pouring substances out of the steam-heater.

small iron tacks. Stand the test-tube, with the thermometer surrounded by the tacks, in a beaker of water, or in a steam-heater, which can be made by fitting a long tin canister with a cork, outlet, and test tube, as shown in Fig. 32. Boil the water.

Observe the temperature of the tacks, and when the water has been steadily boiling for some time, take out the thermometer, cool it under the tap and dry it. Take hold of the test-tube, or of the whole steam-heater, with a duster; quickly pour the tacks into the cold water, tipping the heater as shown in Fig. 33, and observe the temperature of the mixture.

Gain	Mass of water, - - - - - -	...... gm.
	Temperature of water, - - -	......° C.
	" mixture, - - -	......° C.
	Number of degrees through which the temperature of the water was raised,	......° C.
Loss	Mass of iron tacks, - - - -	...... gm.
	Temperature " - - - - -	......° C.
	Number of degrees through which the temperature of the tacks fell, - -	......° C.

(*e*) Repeat the experiment, using 50 grams of water at the same temperature as the tacks had before being put into the cold water. Compare the effect of the tacks in raising the temperature of the cold water with that of the same mass of hot water at the same temperature.

50 gm. of water at ......° C. raised 50 gm. of water at ......° C. through ......° C.

50 gm. of tacks at ......° C. raised 50 gm. of water at ......° C. through ......° C.

(*f*) Cut 50 gm. of thin copper wire into pieces, and repeat the preceding experiment with them instead of iron tacks. Compare, as before, the quantity of heat given up by the copper with that given up by the equal mass of water at the same temperature.

(*g*) Repeat the preceding experiment with 50 gm. of lead shot, and also with 50 gm. of glass beads, and 50 gm. of mercury.

The experiments you have just performed also show you that the same masses of substances at the same temperature have very different quantities of heat in them; in other words, they have different *capacities for heat*.

Arrange the substances you have used in a table, from that which gave up the most heat to that which gave up the least.

Specific Heats.

It has now been seen that a given quantity of water has a greater capacity for heat than the same mass of other substances you have experimented with, viz. lead, iron, copper, glass. When you compare the capacity for heat of any body with water, you will find it is always less. The ratio of the capacity of heat of a body, compared with that of water, is called its *specific heat*. You may formally define specific heat in two ways; either you may say that it is "the ratio of the number of calories required to raise the temperature of a given mass of a substance through a certain number of degrees of temperature compared with that required to raise the temperature of an equal mass of water through the same number of degrees"; or, it is "the number of calories required to raise an unit mass of a substance through 1° C."

Since in measuring the specific heat of a substance the water employed in the experiment must be contained in a vessel of some kind, which in the process gets warmed, and so absorbs some of the heat units, you must first ascertain the number of units of mass of water the vessel, or *calorimeter* as it is called, is equivalent to. This is called the water equivalent of the calorimeter.

33. The Water Equivalent of a Calorimeter.

(*a*) Determine by weighing, the mass in grams of a copper calorimeter. Observe the temperature of the air and consequently of the calorimeter.

Pour into the calorimeter a convenient quantity of warm water at a temperature of from 35° C. to 40° C. Enough to one-third fill the calorimeter is a good amount. Notice with a thermometer, which you should carefully use as a stirrer, that, on pouring the warm water into the cold calorimeter, its temperature falls. When its temperature becomes stationary, which it will soon do, record the temperature again. Determine the

mass of the calorimeter and water. Subtract mass of calorimeter, and so obtain mass of water used.

Mass of calorimeter, - - -	......gm.
Temperature of calorimeter, - -	......° C. $=t°$.
Mass of water, - - - -	......gm. $=M$.
Temperature of water, - - -	......° C. $=T$.
Resulting temperature, - - -	......° C. $=\theta$.

Water equivalent of calorimeter $=w$.

The exchange of heat which takes place may be considered as follows:

Mass of hot water × fall of temperature

......×......

......calories.

This gives the number of heat units used in increasing the temperature of the calorimeter by an observed number of degrees. Find from the result the number of calories required to raise the temperature of the calorimeter through 1° C., that is, the water equivalent or water value of the calorimeter.

It is always best to consider the conditions of the experiment as above described. The exchange of heat may, however, also be regarded as an equation, thus:

$$\left.\begin{matrix}\text{Number of Calories given}\\ \text{out by water}\end{matrix}\right\} = \left\{\begin{matrix}\text{Number of Calories taken}\\ \text{up by the calorimeter.}\end{matrix}\right.$$

$$M\times(T-\theta) \qquad = \qquad w\times(\theta-t);$$

$$\therefore\quad w=\frac{M(T-\theta)}{(\theta-t)}=\text{.........}$$

The number of calories given out by a body in cooling, or the number taken up when its temperature is raised, is always the product of the body's mass (m), the rise or fall of temperature (t) and its specific heat (s), or,

Number of calories concerned $=m\times t\times s=mts$.

Since the specific heat of water is 1, in the case of water the number of calories $=mt$ (see Exercise 31 (*a*)).

34. Determination of the Specific Heat of Solids.

(*a*) Determine by weighing, the mass of the copper calorimeter, the water equivalent of which you have already found. Pour in enough water to one-third fill it. Again weigh. Put a thermometer into the water and leave it to take the temperature of the water. When the temperature is stationary, record it. Weigh out about 50 grams of short pieces of copper wire. Heat the copper in the steam-heater provided, and record the temperature of the copper with a second thermometer. Quickly introduce the hot copper into the cold water, stir, note the rise in temperature of the water, and, when constant, record.

Set down your observations thus :

Mass of calorimeter and water, - -	...... grams.
„ „ alone, - - -	...... „
Therefore mass of water in calorimeter, -	...... „
Water value of calorimeter, - - -	...... „
Total water (m), -	...... „
Temperature of mixture, - - - -	...... ° C.
„ „ water, - - - -	...... „
Therefore rise of temperature (t), - -	...... „
Quantity of heat gained ($m \times t$), - -	...... calories.
Mass of copper, - - - - - -	...... grams.
Temperature of copper before mixing, -	...... ° C.
„ „ mixture, - - - -	...... „
Therefore fall of temperature, - -	...... „

...... grams of copper in falling ...... degrees gave out ...... calories gained by cold water and calorimeter;

therefore

1 gram of copper in falling ...... degrees would give out ...... calories ;

and

1 gram of copper in falling 1° C. would give out ...... calories.

The result thus obtained is the specific heat of copper.

Instead of considering the observations in this way, the result may be obtained by an equation, thus: Let mass of water $= M$; mass of copper $= m$; temperature of calorimeter and water $= t$; temperature of copper $= T$; resulting temperature $= \theta$.

Then

$$\left.\begin{array}{l}\text{Heat given out by}\\ \quad\text{hot copper}\end{array}\right\} = \left\{\begin{array}{l}\text{Heat taken up by cold calori-}\\ \quad\text{meter and water.}\end{array}\right.$$

$$m \times (T-\theta) \times s = \left(\begin{array}{l}\text{water equivalent}\\ \text{of calorimeter } (w)\end{array} + M\right) \times (\theta - t).$$

$$s = \frac{(w+M)(\theta-t)}{m(T-\theta)}.$$

(*b*) Determine specific heats of shot, marble, iron, tacks, coal, and some bronze coins.

35. Specific Heats of Liquids.

When a liquid can be stirred up with water without the production of heat due to chemical action, its specific heat can be found by the method used in the preceding exercises.

(*a*) Weigh a calorimeter. Half fill it with turpentine, and find the mass of the turpentine. Observe the temperature of the turpentine. Observe also the temperature of some boiling water. Pour boiling water into the turpentine; keep the two liquids well stirred, and observe the temperature of the mixture. Find the mass of the water added. From these observations calculate the specific heat of turpentine.

(*b*) Determine in the same way the specific heat of mercury.

When a liquid mixes with water, and heat is thereby produced, its specific heat can be indirectly determined as follows:

(*c*) Fill a calorimeter of known mass about half full of alcohol, and determine the mass of the alcohol. Observe also the temperature of the liquid. Heat about 30 grams of copper to the boiling point of water, as in Exercise 32 (*d*); observe the temperature; and pour the copper into the alcohol. Observe

the temperature of the mixture. Taking the specific heat of copper as 0·095, find the specific heat of the alcohol.

Mass of calorimeter and alcohol, -	...... gram.
" " alone, - - -	...... "
Mass of alcohol, - - - -	...... "
Temperature of mixture, - - - -	...... ° C.
" " alcohol, - - - -	...... "
Rise of temperature, - - - -	...... "
Mass of copper (m), - - - -	...... gram.
Temperature of copper, - - - -	...... ° C.
" " mixture, - - - -	...... "
Fall of temperature (t), - - -	.... "
Number of calories given out by copper ($m \times t \times 0.095$), - - - - -	......
Number of calories used up by calorimeter,	.. ..
" " " " alcohol, -	......

Then

...... grams of alcohol require ...... calories to raise their temperature ...... degrees ;

therefore

1 gram of alcohol requires ...... calories to raise its temperature 1° C. This is the specific heat of alcohol.

(*d*) Determine in the same way the specific heat of glycerine by pouring into a known mass of the liquid, at a certain temperature, some shot (the specific heat of which is known) at an observed temperature, and taking the temperature of the mixture.

36. Latent Heat of Fusion.

(*a*) Weigh about 200 gm. of luke-warm water into a beaker, and observe its temperature. Put a few small pieces of ice into the water, stir them round with the thermometer, and, *as soon as* they have melted, again observe the temperature of the water.

Now determine by weighing the mass of the water, and find out, from the increase of mass, the mass of ice added.

Mass of water, - - - - -	...... gm.
Temperature of water, - - - -	......° C.
" " when the ice had melted,	......° C.
Fall of temperature, - - - -	......° C.
Mass of water and mass of melted ice, -	...... gm.
Therefore mass of ice added, - - -	...... gm.

The loss and gain of heat may be shown in two columns thus:

GAIN.	LOSS.
...... gm. of water fell through ......° C.; quantity of heat lost equals mass of water × fall of temperature. =.........	...... gm. of ice were melted to water at 0° C. ...... gm. of water at 0° C. were raised to ......° C., that is, through ......° C.; therefore the quantity of heat used equals mass of water (melted ice) × rise of temperature.

You see how much heat was expended, and you also see that only a part of it was used in heating the melted ice from 0° C. to the final temperature. The difference between the two results gives you the amount of heat expended in melting the mass of ice used. Find the amount of heat required to just melt 1 gm. of ice. This is called the *latent heat of water*, or the latent heat of fusion of ice.

37. Latent Heat of Vaporisation.

(*a*) Pour a few drops of any very volatile liquid, such as ether or alcohol, upon the hand. It soon disappears, and as a result of its disappearance the hand feels very cold.

The heat necessary to effect the change of state has been taken from the hand.

(*b*) Place a few drops of water between the bottom of a small beaker and a block of wood. Put some ether into the beaker

and blow gently over it with a pair of bellows having a tube fastened to the nozzle. The water will freeze.

(*c*) Wrap a piece of muslin once round the bulb of a thermometer and secure it with thread. Hang the thermometer from a convenient support, and observe the temperature indicated by it. Pour a little ether or other volatile liquid upon the muslin and again observe the temperature indicated by the thermometer.

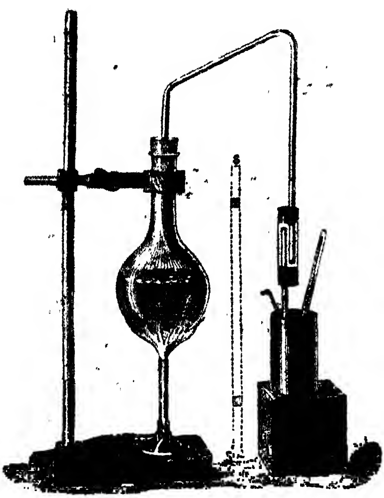


FIG. 34.—Flask fitted with tube and water-trap for the determination of the latent heat of steam.

(*d*) Into the flask used in previous experiments fit a glass tube and connections as in Fig. 34. The short length of wider glass tube is a trap to catch condensed steam. Put some water into the flask and boil it. While the water is getting hot, weigh out about 300 gm. of water in a beaker or a thin metal vessel, and observe its temperature. After steam has been issuing from the glass tube for a few minutes, place the beaker so that the end of the tube is well under the water, and let it stay there until the water reaches a temperature of about 40° C. Then weigh the water again to find the mass of steam condensed.

Mass of water, - - - - - -	...... gm.
Temperature of water at beginning, -	......° C.
" " end, - - -	......° C.
Rise of temperature, - - - - -	......° C.
Mass of water + mass of condensed steam,	...... gm.
Therefore mass of condensed steam, -	...... gm.

As before, the changes of temperature can be arranged under two heads:

Loss.	Gain.
...... gm. of water were raised through ......° C. The quantity of heat used equals mass of water × rise of temperature.	...... gm. of steam were condensed to water at 100° C. ...... gm. of water at 100° C. fell to ......° C., that is, through ......° C., and the quantity of heat thus given up equals mass of condensed steam (water) × fall of temperature.

You thus see the quantity of heat gained, and how much of the gain was due to condensed steam falling from 100° C. to the final temperature. The remainder shows you the amount of heat given up by a certain mass of steam in condensing into water. Find the amount of heat given up by 1 gm. of steam in condensing to form 1 gm. of water. This is called the *latent heat of steam*, or the latent heat of vaporisation of water.

Good determinations of the latent heat of steam can be obtained in the following simple way:

(*c*) To a test-tube of about 1 inch diameter fit a cork through which passes a short glass tube bent at a right angle. About half an inch from the open end inside the test-tube a hole is blown in the side of the glass tube (Fig. 35). Boil water in the test-tube, and when steam is issuing freely, place a weighed calorimeter containing water, the mass and temperature of which have been observed, so that the end of the tube from which steam is issuing is immersed in the water. The calorimeter may be wrapped in cotton wool and placed in an outer vessel if desired, and the flame screened by a note-book. After the temperature has risen

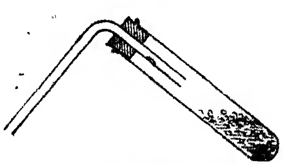


FIG. 35.—Test-tube fitted for the determination of the latent heat of steam.

to about 40° remove the calorimeter—do not remove the test-tube from the flame—observe the temperature, and again weigh. Calculate as before. In this case, owing to the side hole in the glass tube, any water collecting in the tube drops back into the test-tube and is not blown over with the steam.

CHAPTER V.

INTENSITY AND REFLECTION OF LIGHT.

38. Photometery and Law of Inverse Squares.

(*a*) PIN a piece of white paper upon a drawing board to act as a screen. Fix the drawing board at right angles to a table in a darkened room. In front of the screen place a vertical rod about 1 to 2 cms. in diameter (a retort stand will do). Beyond this, place to one side, a candle fixed on a piece of wood, and to the other side two candles, one immediately in front of the other, fixed on a block of wood. Notice that two shadows of the upright appear on the screen. Move the candles near each other so that the two shadows of the upright touch but do not overlap. Notice that one shadow, that cast by the two candles, is darker than the other. The latter shadow is illuminated by one candle, the other is illuminated by two candles. Now, move back the two candles until the shadows appear equally dark, that is, in equal contrast with the bright part of the screen. Then the two candles give just as much light to the screen as the one. Measure the distance of the one candle, and the mean dista[illegible] e two. Compare these distances; are they in the ratio [illegible] Compare also the squares of the distances.

Do [illegible]e experiment with different distances, and again compare the squares of the distance. Hence prove that the *illumination is inversely proportional to the square of the distance.*

(*b*) Using the same screen and rod as before, compare the illuminating power of a candle flame with that of a fish-tail gas burner or a lamp (Fig. 36). Place the candle, which can be conveniently fixed on a flat piece of wood, at a measured distance from the screen, say 30 cm. Move the lamp away from the screen until the shadows cast by the candle flame and the lamp flame are of equal intensity To accurately estimate this

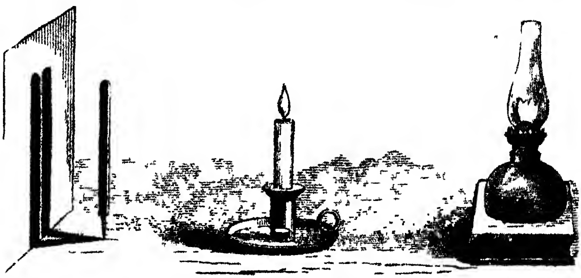


FIG. 36 —Comparison of the intensities of the flame of a candle and lamp.

you must arrange the flames so that they are the same height from the table, and in such positions that the two shadows on the screen just touch but do not overlap one another.

The relative darkness of the shadows is more easily seen if the eyes be contracted or half closed, especially when, as here, the light is of somewhat different colours.

Measure the distance of the lamp flame from the screen. Vary the distance of the candle from the screen, and find the corresponding proper position of the lamp flame. Record.

The Shadow Photometer (Rumford).

Distance of Candle from the Screen.	Distance of Lamp Flame from the Screen.
1	
2	
3	
4	

Compare the squares of these distances. These are evidently the ratios of the relative illuminating powers of the two sources of light; and hence the comparison shows the *candle power* of the lamp or gas flame used.

39. Laws of Reflection.

(*a*) Fix two strips of wood at right angles as in Fig. 37, *AB*, *CD*. Against the upright slab place a piece of glass, *EF*, with blackened back so that reflection only takes place from the front. Upon the horizontal slab place a sheet of white paper. Notice that the reflected paper appears in the same plane as the paper itself when the mirror is vertical. Stick a pin, *b*, in the wood against the glass, and place another pin near the position *a*. Now procure another pin and stick it into the wood at *c* in such a position that *c*, *b*, and the image of *a* are in a straight line. Draw with a finely pointed pencil a line along the edge of the glass *xy*: then take glass and pins away.

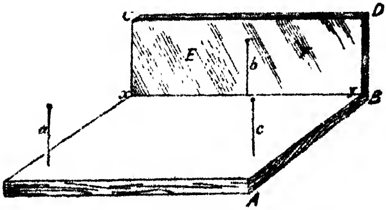


FIG. 37.—Pin method of determining the laws of reflection of light.

The paper will be marked by the pinholes and the line *xy* (Fig. 38). Draw lines through the pinholes, and at *b* a normal to *xy*, that is, a line, *bd*, perpendicular to *xy*. Measure the angles *abd*, *cbd* with your protractor and compare them. Repeat the experiment two or three times, with the pins in different positions, and so determine that *the angle of incidence and the angle of reflection are equal.*

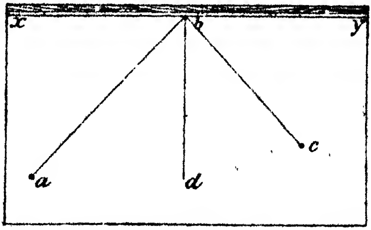


FIG. 38.—Angles of incidence and reflection of light.

Observe that since the holes made by the pins are all on the same piece of paper with the normal, *the incident ray, the normal, and the reflected ray are all in the same plane.* Moreover, the reflected ray is on the opposite side of the normal from the incident ray.

40. Images formed by Plane Mirrors.

(*a*) Place a knitting needle in front of a plane unsilvered sheet of glass fixed vertically in front of a dark background. Arrange another such needle behind the mirror in such a position that wherever the eye be placed, the needle behind the mirror always appears in the position of the reflected image of the first needle in the mirror.

It is easy to arrange the needle in the right position behind the mirror, by observing that when this needle apparently moves more in the direction in which the eye is moved than the image does, the needle is too far behind the mirror and *vice versa*.

Measure the distances of the two needles from the back of the mirror. They should be the same, thus showing that the image is situated as far behind a plane mirror as the object is in front of it.

(*b*). Arrange two strips of looking-glass about an inch wide, parallel to one another, about two or three inches apart, and at right angles to a piece of drawing paper pinned on a drawing board. Stick a pin into the paper between the mirrors at a distance of an inch from one mirror. Using pins which are longer than the height of the strips of looking-glass, and adopting the plan described in the last experiment, mark the position the first two or three images of the object appear to occupy. Remove the mirrors, join the positions of the pins with a straight line, and write down what you discover from the experiment.

(*c*) Obtain two pieces of looking-glass, each about 6×6 inches. Connect an edge of one piece with an edge of the other with a strip of tape, so as to form a hinge. Place the mirrors upon the table, with the hinged edges vertical, and

the faces of the mirrors at right angles to each other. Put a lighted candle between the two mirrors, and observe the number and positions of the images seen. Make a sketch of what you see. Place the mirrors so that the angle between them is 45° and also so that it is 60°. Sketch the images seen in each case. Record the number of images and the angles between the mirrors, and use the numbers to determine the values for columns three and four below. Compare these columns and express in words the conclusions they suggest.

Angle between Mirrors.	Number of Images (n).	$\frac{360}{\text{Angle between Mirrors}}$	

41. Concave Mirrors.

(*a*) Fix a concave mirror vertically on any convenient support. In front of it place a cork with a pin stuck in vertically, and observe that in some positions of the pin an upright magnified image is seen in the mirror, while in others an inverted image is seen. Move the cork and pin until this inverted image appears to coincide with the pin itself (this being seen by moving the head as described in Exp. 40 (*a*)). When this is the case, measure the distance of the pin from the mirror. The result is the radius of curvature of the mirror. Consider why this is so.

(*b*) Arrange a concave mirror, screen, and lamp as shown in Fig. 39. The light of the lamp passes through a small hole in the screen having fine wires or threads fixed across it at right angles. Move the mirror until a distinct image of the cross-wires can be seen upon the screen near the hole. When this is the case the distance between the screen and the mirror is the radius of curvature.

(*c*) Cover the concave mirror with black paper, except a small part at the centre. In this way the aperture of the mirror is

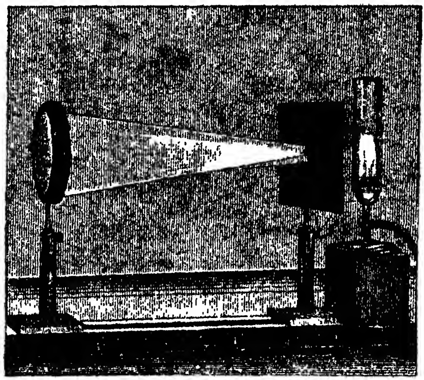


Fig. 39.—Determination of the radius of curvature of a concave mirror.

made small. Allow rays of sunlight to fall upon the mirror (these come from so great a distance that they can be considered *parallel*). Move a very small paper screen up and down in front of the reflecting surface so as not to cut off the incident rays. Notice that at a certain point a clear image of the sun is formed, and probably the screen will be burnt.

The point so obtained is called the *principal focus* of the mirror. In Fig. 40, *F* represents this point and *C* the centre

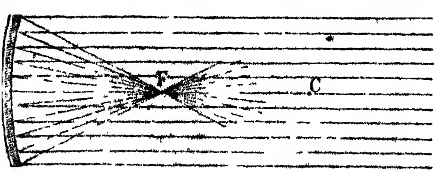


Fig. 40.—Principal focus (F) and centre of curvature (C) of a concave mirror.

of curvature. The parallel lines show the direction of the sun's rays. This point *F*, is midway between the mirror and *C*, or the *focal length* is half the radius of curvature.

Compare the focal length with the radius of curvature. You will find that focal length = ½ radius of curvature, or expressed by symbols, $f=\frac{r}{2}$.

(*d*) Place a light and a paper screen on the same side of the concave mirror. Move them until the image of the flame on the screen is as distinct as possible. Carefully measure the distances d_1 and d_2 of the light and the screen from the mirror, and calculate the value of the expression $\frac{1}{d_1}+\frac{1}{d_2}$. Observe that this is constant.

If d_1 is infinitely distant, as in Experiment 41 (*c*), it is evident that $\frac{1}{d_1}=0$, and the expression becomes $\frac{1}{d_2}$, that is, $\frac{1}{F}$. Hence $\frac{1}{d_1}+\frac{1}{d_2}=\frac{1}{F}$.

Using this formula, calculate the focal length of the mirror. Perform several experiments and record thus:

Distance of Light from Mirror $=d_1$.	Distance of Screen from Mirror $=d_2$.	Principal Focal Length calculated from Formula.

(*e*) Arrange the mirror, screen, and light as in the last experiment and use a candle flame or a small gas jet.

i. Place the light in the principal focus of the mirror, and observe that you can obtain no image on the screen. Why is this?

ii. Place the light at the centre of curvature of the mirror. Where is the image formed?

iii. Place the light in any position farther away from the mirror than the centre of curvature. Determine the position of the image. It is always located between the principal focus and the centre of curvature. Also observe the image is in every such case *real, smaller than the object, and inverted.*

(*f*) Cut a circular aperture in a piece of card and measure its diameter. Place the card in front of the candle, between the candle and the mirror, and move the screen until the image is clear and in good focus. Measure the diameter of the image, and also the distances of the screen and the circular aperture from the mirror. Hence prove that

$$\frac{\text{dist. of object}}{\text{dist. of image}} = \frac{\text{diam. of object}}{\text{diam. of image}}.$$

In other words, the linear dimensions of object and image are in the same ratio as their distances from the mirror.

(*g*) Place the light in any position between the principal focus and the centre of curvature. Using a larger screen, determine the position of the image. It is always situated somewhere outside the centre of curvature. Also observe that the image is in every such case *real, larger than the object, and inverted*

(*h*) Having obtained the position of the image either as in (*e*) iii. or (*f*), interchange the light and the screen. Observe that the image is formed where the light originally was. These interchangeable positions are called *conjugate foci.*

(*i*) Place the light between the mirror and the principal focus. Observe that the image appears in the mirror. It is not real, because it cannot be formed on the screen. It is called *virtual.* The image is *larger than the object, and is erect, not inverted.*

42 Convex Mirrors.

(*a*) Substitute a convex mirror for the concave one used in the preceding exercises. Observe that wherever the light is placed the image is formed behind the mirror, that is, it is always *virtual.* Notice also that the image is *erect*, and *smaller* than the object.

(*b*) Fix the convex mirror in a convenient support. Place a pin, *B*, in front of the mirror at the distance of 3 or 4 inches Then at *C* and *D* place two pins so that they appear to be in a line with the image of *B*. Do the same at C_1 and D_1. Then

mark the position of the mirror, and remove the pins. Join CD C_1D_1, and produce them to meet in B_1. This is the virtual image of B. Observe it is nearer to the mirror than B. Mea-

FIG. 41.—Determination of the focal length of a convex mirror.

sure the distance of B and B_1 from the mirror. Call them d_1 and d_2. Then $\frac{1}{d_1} - \frac{1}{d_2}$ is the focal length of the mirror.

CHAPTER VI.

REFRACTION OF LIGHT.

43. Refraction at one Plane Surface.

(*a*) Obtain a rectangular metal box, such as a cigarette box, and put a wooden or metal scale on the bottom. In a darkened room let sunlight fall slantwise against the edge. The side of the box throws a shadow which reaches, say, to C (Fig. 42), which, since light travels in straight lines in the same medium, is a continuation of the rays of sunlight AB. Without disturbing anything, fill the box with water. The shadow

no longer reaches to *C*, but only as far as *D*. Clearly the light waves have been bent or refracted out of their original course. Notice that *NN'* is the normal, and that the light travelling

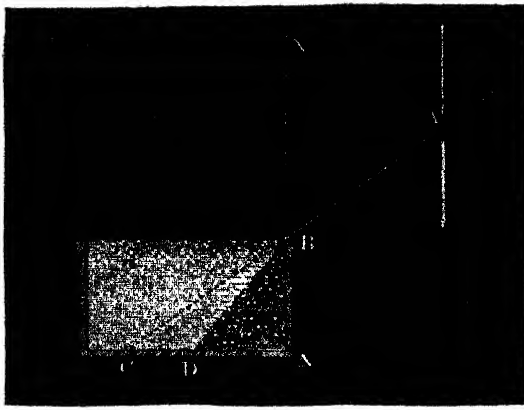


FIG. 42.—Refraction of light by water in a trough.

from the comparatively rare air into the comparatively dense water is refracted towards the normal.

This experiment illustrates the general fact of the deviation experienced by a ray of light in passing from one medium to another of different density. The laws of refraction can be determined by a simple experiment.

44. Refraction at two Plane Surfaces.

(*a*) Upon a piece of board, *ABCD* (Fig. 43), place a sheet of paper, and upon the paper put a piece of fairly thick glass, *EF*, with parallel sides (a thick piece of glass from a box of weights, a paper weight, or a number of slips of microscope glass, or several strips of window glass tied

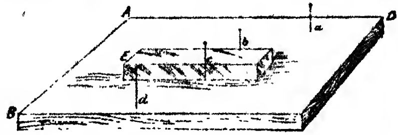


FIG. 43.—Pin method of determining refraction by a rectangular block of glass.

together will do very well). Rule along the edges of the glass with a finely pointed pencil. Place two pins, a, b, as shown in the illustration, and then, *looking through the glass* from the other side, stick in the pins c, d so that all four appear in a straight line.

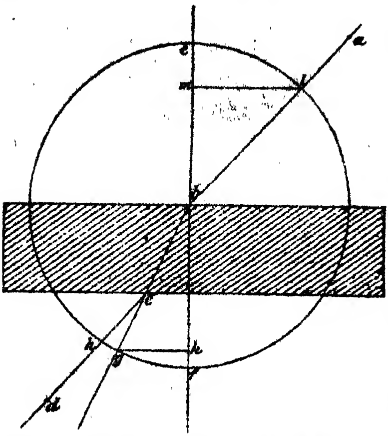


FIG. 44.—Laws of refraction determined by the pin method.

Now take away the glass and pins and join the pin-holes on the paper as shown in Fig. 44. Draw the normal *ebf*, and the circle *elfg*. Draw *lm* and *gk* perpendicular to *ebf*, and compare the lengths *lm*, *gk*. Obtain the ratio $\frac{lm}{gk}$ for different positions of the pins; it will be found practically the same in all cases in which the same material is used.

Notice that the direction of the ray *cd*, emerging from the glass, is parallel to that of *ab*.

These experiments will enable the general rules of refraction to be well understood. The laws of refraction are:

1. *The incident ray, the normal, and the refracted ray are all in the same plane. The incident and refracted rays are on opposite sides of the normal.*

2. *If a circle be described about the point of incidence, and perpendiculars be dropped upon the normal from the intersections of this circle with the incident and refracted rays, the ratio of the lengths of these perpendiculars is constant for any two given media. This ratio is called the index of refraction of the substance.*

45. Additional Methods of Determining the Index of Refraction.

(*a*) Cut a circular piece out of ruled paper and place it at the bottom of a jar of water. From the same sheet cut a semi-circular piece to fit the outside of the jar. Place this around the bottom of the jar outside, and look down the jar. The lines of the inside piece appear farther apart than those of the outer, that is, it appears to be higher. Raise the outside piece until the lines appear of equal distance apart. Measure the distance of the two pieces from the surface of the water. Then

real depth ÷ apparent depth = index of refraction.

(*b*) Using similarly a piece of ruled paper cut in two, place one piece under a slab of glass about an inch thick (several pieces placed together will do), and raise the other piece by putting cards below until the distance between the lines appears equal to that on the piece below the glass. Count the number of

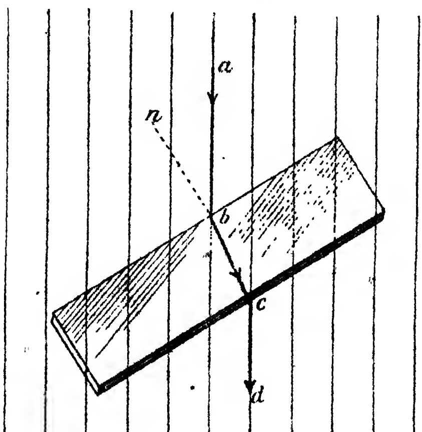


FIG. 45.—To illustrate Exercise 45 (*c*).

cards required, and find the whole number giving a thickness equal to that of the glass. Suppose these numbers are *a* and *b*,

(*b*) Find the focal length of a convex lens by forming a

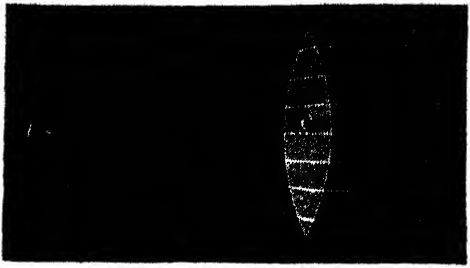


FIG. 47.—Principal focus of a lens

distinct image of the sun upon a screen, and determining the distance of the screen from the lens.

48. Indirect Method of finding Focal Length of a Convex Lens.

(*a*) Arrange a lens in a clip on a stand. On one side of it place a small gas jet or a lighted candle, and on the other side a screen (Fig. 48). Adjust the distances of the light and screen until a clear image is obtained. Repeat the experiment for

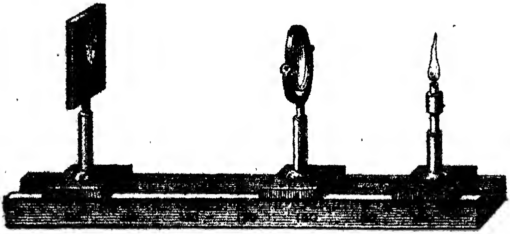


FIG. 48.—Formation of image by lens.

several positions of the light. Measure the distances of the light (d_1) and screen (d_2) from the lens. By the same reasoning as

was employed in the experiments with a concave mirror (pp. 54-7), it can be shown that

$$\frac{1}{d_1}+\frac{1}{d_2}=\frac{1}{F}$$

Use this equation to determine the focal length of the lens you are using.

It is a good plan, in order to be sure of an accurate result, to arrange cross wires in front of the light and to use these as the object. Punch a circular hole in a piece of cardboard, and stick, by means of sealing wax, two pieces of fine copper wire across the hole at right angles. (Fig. 39.)

(*b*) Arrange a light screen, as shown in Fig. 39, but in the place of the mirror put a convex lens having a plane mirror close behind it. By slightly turning the mirror in one direction or another an image of the cross wires can be seen near the hole in the screen. Move the lens until this image is distinct. The distance between the lens and the screen is then the focal length required.

In this experiment the reflected rays travel back along the same paths as the incident rays. The only rays that can be reflected from the mirror in the same paths as they strike the mirror are those that are normal to the surface. The mirror thus reflects rays which are parallel to one another, and the distance of the lens from the screen when the reflected image is distinct is therefore the focal length.

49. Relation of Image to Object.

(*a*) Having obtained the position of the image as in Exercise 48(*a*), interchange the cross wires and screen and satisfy yourself that the image is now formed where the object originally was. Repeat for other positions. Such pairs of positions are called *conjugate foci*. Notice that in both experiments the image is inverted.

(*b*) Place a convex lens at such a distance from a small object, for instance the print on this page, that the object is between the principal focus and the lens. Notice that the print is

magnified—in other words, the image is on the same *side of the lens as the object, and is erect and magnified.*

A lens used in this way constitutes a simple microscope.

(*c*) Arrange the cross wires, lens, and screen as in Experiment 48(*a*). When a clear image is obtained measure the distance of the cross wires and also of the screen from the lens. Similarly measure the size of the cross-wires and of the image. Prove:

$$\frac{\text{size of image}}{\text{size of object}}=\frac{\text{distance of image}}{\text{distance of object}}.$$

50. Principle of Astronomical Telescope.

(*a*) Fix a convex lens of a long focal length to form a real image of any object AB on a card placed at ab (Fig. 49). Next place on the other side of the card a convex lens of a short focal

FIG. 49.—To illustrate the principle of construction of an astronomical telescope.

length in such a position that, looking through it, writing on the card is seen clearly magnified. If the card is taken away the image formed by the first lens is seen magnified. Such an arrangement of lenses forms the ordinary astronomical telescope.

51. Focal Length of Concave Lens.

(*a*) Though there is no real image formed by a concave lens, its focal length may be obtained by combining the lens with a stronger convex lens. Measure the focal length (1) of the convex lens itself $=F$ and (2) of the combination of concave and convex lenses $=F_1$, by Experiment 48(*b*). Calculate the focal length f of the concave lens by the formula:

$$\frac{1}{f}=\frac{1}{F}-\frac{1}{F_1}.$$

CHAPTER VII.

COMPOSITION AND ANALYSIS OF LIGHT.

52. Composite Nature of Light.

(*a*) *Dispersion by a Prism.*—In a piece of card cut a slit about 2 cm. long and 2 mm. wide. Place the card, with the slit vertical, in front of a fish-tail gas flame. Arrange a prism on a stand so that it is of the same height as the slit, and has its refracting edge vertical. Put the prism a *short distance from the slit*, and look into it so as to see the image of the slit

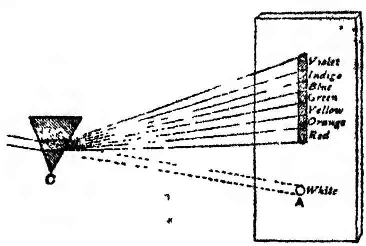


FIG. 50.—Decomposition of light by a prism.

Observe that the light is refracted towards the base of the prism and that it is decomposed into constituent colours, which are differently bent by the prism. The violet light is refracted most and the red light least. Colours between these limits are bent by intermediate amounts. Name the colours you can see.

> The band of colour is called a *spectrum*; the light is said to be *dispersed* by the prism. The *refrangibility* of violet light is greater than that of red.

(*b*) *Increase of Dispersive Action.*—Place a second prism by the side of the first, with its base in the same direction. Observe

that the light is bent still more out of its course, and also that the band of colour is longer, or the distance between the extreme violet and the extreme red is much greater than with one prism. The *dispersive power* of the two prisms is thus greater than that of one.

(*c*) *Recomposition of Light.*—Reverse the position of the second prism, that is, arrange it so that its refracting angle

FIG. 51.—Recomposition of light.

is in the same direction as the base of the first (Fig. 51). The band of colour disappears; thus the effect of the second prism is to neutralise the dispersive action of the first.

(*d*) *Minimum Deviation.*—Arrange a prism and slit as in the preceding exercise, but instead of a gas flame use a Bunsen burner, coloured yellow by sprinkling salt over it. Notice that only a single yellow image of the slit is now seen. Turn the prism and observe that the displacement of the image from the original direction of the beams from the slit changes, and that for one position of the prism it becomes a *minimum*, the displacement increasing in whichever direction the prism is turned.

Observe that in this position of *minimum deviation* the light passes symmetrically through the prism, making equal angles with the sides both when incidence and emergence occurs. Observe also that the image of the slit appears brightest when the prism is in the position of minimum deviation. [See Exercise 46(*b*).]

53. The Spectroscope.

A spectroscope (Fig. 52) consists essentially of one or more prisms, *P*, with a collimator, *C*, having a slit at one end for limiting the breadth of the beam and making the rays parallel, and a small telescope, *T*, for viewing the analysed light.

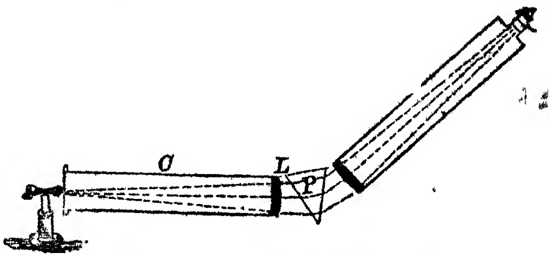


FIG. 52 —Essential parts of a spectroscope

(*a*) Examine your spectroscope and compare its parts with hose shown in Fig. 52. Adjust the prism for minimum leviation by rotating it in the manner described in Exercise ¦6(*b*).

54. Continuous and Bright Line Spectra.

(*a*) Place a fish-tail burner a few inches in front of the slit of he spectroscope and examine the light by looking through he telescope. You will see a continuous band of colour. Examine also the light radiated by a white hot crucible and y a lighted candle.

(*b*) Examine the non-luminous flame of a Bunsen burner by neans of the spectroscope. While looking through the telescope, let somebody hold in the flame a piece of platinum wire noistened with a strong solution of common salt. Instead of a continuous spectrum you obtain a single bright yellow line, which may, however, be seen as a double line if your prism s capable of dividing it. Using another platinum wire, substi-

tute a solution of washing soda or other compound of sodium for the common salt solution. Observe that you still obtain the same yellow line as before.

(*c*) Repeat the experiment, using a clean platinum wire in each case, and employing, in order, solutions of the chlorides of lithium, thallium, strontium, and calcium.

(*d*) Examine the spectrum of magnesium by burning magnesium ribbon a few inches in front of, and just below, the slit.

These experiments show that when certain substances are converted into gas, the vapours emit light of definite colours, and each substance has particular colours of its own. An incandescent or white hot substance, however, emits light of all colours. Every coloured line seen in the former case is really a coloured image of the slit of the spectroscope. When an infinite number of these coloured images are arranged together, a continuous spectrum is produced.

55. Effects of Absorption of Light.

(*a*) Introduce sheets of coloured glass between the slit and the flame of a fish-tail burner and observe the effects produced. Carefully record your observations.

The coloured glasses *absorb* certain constituents of white light. Thus, a blue glass absorbs all the colours except the blue, indigo, and violet. A red glass similarly absorbs all the light except the red and perhaps some of the orange.

(*b*) Place a piece of deep green glass and a piece of ruby red glass together between the slit and the light. All the colours are absorbed, and nothing is seen on looking through the telescope.

(*c*) Take a piece of ruby red glass and a piece of deep green glass. Why do they appear red and green? View their absorptive spectra.

What coloured light passes through the green glass? Look at some red, yellow, blue, green, etc., objects through this, and

explain why they appear of the colours you see. Do the same with the red glass.

(*d*) Take the two glasses in a dark room with two candles. Place a screen upright, and in front of it place a candle and the red glass. What colour does the screen appear?

Do the same with the green glass, and then place both glasses alongside with a candle behind each, so that the screen is illuminated by light through each. What colour does it appear, and why?

(*e*) Introduce a test tube containing some copper turnings and moderately dilute nitric acid, between the light and the slit. On looking through the telescope the spectrum will be seen to be traversed by a series of dark bands. The brown gas evolved from the nitric acid has the power of absorbing certain of the constituents of the white light, and the black bands occur in the places of the light which has been thus absorbed.

(*f*) Place a few crystals of iodine in a test-tube plugged with cotton wool. Heat the test-tube in a Bunsen burner flame, and then hold in front of the slit as before and observe the absorption spectrum of iodine vapour. Draw a picture of what you see.

56. Selective Absorption with Reference to Dark Lines in the Spectrum of Sunlight.

(*a*) Burn a little salt, or better, a piece of metallic sodium, in spirit lamp or Bunsen burner placed near the slit of the spectroscope. While the substance is burning, start an oxy-hydrogen lime-light so that its beams have to pass through the sodium flame to reach the slit of the spectroscope. The sodium lines will be seen not *bright* as before, but as *dark* lines upon a continuous spectrum. Turn off the incandescent light, or block it out by means of a screen, and the sodium lines will again be seen bright and alone.

The flame is not altered by the light passing through it. It may therefore be concluded that the lines are seen dark by contrast with the bright continuous spectrum of the

lime-light. By placing lithium, or thallium, or any other substance upon the flame, and passing the beams from the incandescent cylinder of lime through it, each set of lines is seen dark upon a continuous spectrum instead of appearing as bright and differently coloured images of the slit. Thus, each element burning in the flame blocks out from the continuous spectrum the lines of which its own spectrum consists.

(*b*) Reflect sunlight through the slit of the spectroscope by means of a mirror. Examine the spectrum. Observe that it is traversed by dark lines. These are produced by the sun's atmosphere absorbing the light of the nucleus just as the substances in the preceding experiment absorbed light from the lime-light.

(*c*) Burn a little salt in a flame and observe the spectrum. Adjust the telescope so that the vertical wire or pointer seen in it is exactly over the yellow line. Then without disturbing the adjustment or the prism, turn the spectroscope towards sunlight and observe the spectrum. Is there a dark line having the same position as the sodium line upon which the pointer had been placed? If so, the coincidence, considered in connection with what you have previously learnt, suggests that sodium exists in the sun's atmosphere in the form of vapour. See whether any other bright line spectra are coincident with lines in the solar spectrum.

CHAPTER VIII.

SOUND: TRANSVERSE VIBRATIONS.

57. Sound is the Result of Vibration.

(*a*) SOUND the tuning fork provided, either by knocking it on the table or by bowing the prongs. Place the prongs gently against the teeth. You will have no difficulty in perceiving that the prongs are in a state of rapid vibration.

(*b*) Sound the tuning fork while it is resting on its sounding board. Bring near it a pith ball pendulum, allowing the ball to touch one of the prongs. Notice that the vibrations of the fork are imparted to the pith ball.

(*c*) Invert a bell jar, and fix it in a clamp. Set it vibrating by bowing the rim. Bring up the pith ball pendulum, and observe that it is set into rapid vibration.

(*d*) Sprinkle sand on a sounding drum or tambourine, and examine the vibration of the sand grains.

(*e*) Pluck a violin or other stretched string and release it, observe the spindle-shaped appearance owing to the rapid vibration of the string. Note also that the breadth of the spindle, *i.e.* the *amplitude* of the vibration, decreases as the sound becomes fainter.

58. The Vibration of a Tuning Fork.

(*a*) Examine the motion of a tuning fork. Fix, by means of soft wax, a flexible style to the end of the prong of the fork provided. A good style can be made by means of a small piece of thin iron wire or by drawing out a piece of soft glass tubing in a gas flame. Blacken a sheet of glass over a gas flame. In

blackening glass, a piece of either wool or blotting paper moistened with benzine or turpentine gives a fine smoky flame, and there is no danger of cracking the glass. Strike the fork

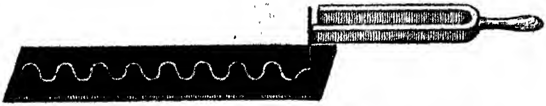


FIG. 53.—Vibrations of a tuning fork traced upon smoked glass.

and draw the style over the glass. A wavy line will thus be scratched (Fig. 53). Examine this line.

(*b*) Simultaneously draw two forks, giving different notes, over a sheet of smoked glass. Find the number of undulations in the lines drawn by each fork in traversing a given distance. These are in the proportion of the number of vibrations made by the forks in a second.

(*c*) Hold the tuning fork in the right hand and a sheet of lightly smoked glass in the left; strike the tuning fork sharply on a pad and hang it up so that the style touches the smoked surface, then immediately drop the glass. After one or two attempts, a good tracing of the vibration will be obtained. Mark the point where the tuning fork first touched the glass, and another near the end of the traced line. Count the vibrations between these two marks, and measure their distance apart. Calculate the time the plate took to fall this distance and so determine the number of vibrations per second.

It has been shown in Part I. (p. 162) that the formula $s=\frac{1}{2}gt^2$ holds good for a falling body, where s represents the space fallen through, g the acceleration due to gravity, and t the time of fall. By means of the preceding exercise you determine s, and you know the value of g, viz. 32·2 feet per second. You can therefore determine t, for, evidently, $t^2=\frac{2s}{g}$. Having found t and the number of waves in the space through which the glass falls in the time t, you can calculate how many waves would be produced in one second, that is, the number of vibrations per second of the fork.

Instead of holding the glass plate and fork in the hands, they may be fixed as shown in Fig. 54. The fork F is then set in vibration by bowing the prongs; and while it is vibrating, the thread around the pins n, n_1 is burnt, causing the plate to fall. The same measurements and calculations are then made as before.

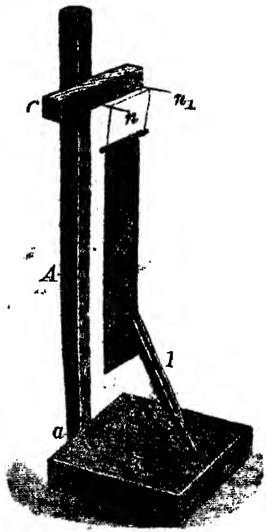


FIG. 54.—Dropping plate apparatus for determining the frequency of a tuning fork.

59. Construction of a Monochord or Sonometer.[1]

(*a*) Take a stout board 3 feet long and 4 inches wide. At 1 inch from one end and $1\frac{1}{2}$ inches apart make holes for and screw in two iron screws, leaving their heads about $\frac{1}{8}$ inch above the board; the holes are to be so bored that the heads of the screws are slightly inclined towards the end of the board. In corresponding positions at the other end of the board fix a small pulley and an iron wrest pin at an angle of 45°. The pulley is to be near enough to the end of the board to allow a wire passing over it to hang freely, and of such a height that the wire rests upon but is only just deflected by the end bridge; the wrest pin is to fit the hole stiffly so that it may be turned with a key. Cut two hard wood bridges 3 inches × $1\frac{1}{4}$ inches × $\frac{3}{4}$ inch, bevel the upper side of each bridge to a blunt edge, and along this edge fix a stout brass wire for the stretched wires to bear upon. Glue the bridges in position equidistant from the ends of the board with the centres of the brass wires exactly 30 inches apart. Make a paper scale 30 inches long divided into $\frac{1}{8}$ inches and fix on the board between the bridges. Twist a loop on the end of a steel or other wire about 3 feet 6 inches

[1] Adapted from the syllabus of the course of Practical Physics at the Royal College of Science, South Kensington.

long, and slip it over the head of the screw on the board, pass the other end through the wrest pin. This wire we shall refer to as our fixed wire. Place a similar wire on the other screw and over the pulley, making a loop at the pulley end for hanging weights. Make two hard wood movable bridges $\frac{1}{8}$ inch higher

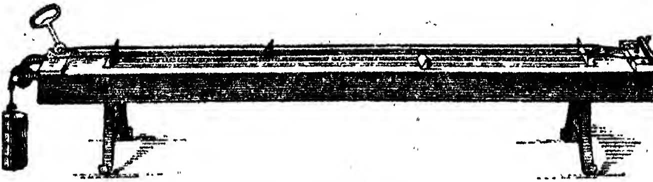


FIG. 55.—A monochord.

than the end ones and also faced with brass wire. The instrument thus constructed will be similar to that shown in Fig. 55.

60. Experiments with a Monochord.

(*a*) Tighten the wire of the monochord until it vibrates, giving a musical note. Place in the bridge and move it, and, plucking the wire, observe that the note emitted is higher when the wire is shortened.

Take the two forks, the frequencies of which have already been compared; move the bridge until the wire emits the same note as fork 1, and measure the length of the vibrating wire; do the same for fork 2.

Compare $\dfrac{\text{length } 1}{\text{length } 2}$ with $\dfrac{\text{frequency } 2}{\text{frequency } 1}$.

and thence deduce that the *number of vibrations per second is inversely proportional to the length of the wire.*

(*b*) At the intervals corresponding to $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, and $\frac{1}{2}$ of the length of the fixed wire mark the letters *D*, *E*, *F*, *G*, *A*, *B*, and *C*, on the scale of your monochord. By means of the key placed over the wrest pin, alter the tension of the fixed wire till it is in tune with the fork given you when the movable bridge is placed on the letter of the scale corresponding to that of the fork.

Now place the movable bridge successively at the other intervals, and observe the sequence of the notes when the wire is set in vibration by plucking. These notes are those of the musical gamut.

It has been seen that the vibration number of the note emitted by the sounding wire is inversely proportional to the length of the string, that is, the shorter the string the higher the note, and inasmuch as the intervals marked on the scale have been arranged in the inverse ratio of the vibration number of the gamut, you have in your experiment obtained the notes of the gamut.

(*c*) From the above see that the frequency ratios in the gamut are—24, 27, 30, 32, 36, 40, 45, 48; the last note, having a frequency double that of the first, being termed its *octave*.

61. Variation of Note with the Mass of Unit Length of Vibrating String.

(*a*) Stretch a second wire, *A*, on your monochord by means of a load of say 14 lbs. attached to the end of the wire which passes over the pulley. Find the length of the fixed wire which gives a note in unison with this second wire. Substitute another wire, *B*, of any material, and stretch it by the same load; find the length of the fixed wire which gives a note in unison with this also. Next cut off equal lengths of the two wires employed, find their masses, and compare them thus:

Lengths of Fixed Wire.	Relative Frequencies of Movable Wires.	Relative Masses of Unit-Length of Wire.
B		
A		

It will be found that the relative frequencies are in the inverse ratio of the square root of the relative masses, that is

$$\frac{\text{frequency } B}{\text{frequency } A} = \sqrt{\frac{\text{mass 1 cm. of } A}{\text{mass 1 cm. of } B}}$$

Hence it follows that if wires of the same material be employed the frequencies are in the inverse ratio of the diameters. The following experiment proves this.

62. Variation of the Note with the Diameter of a String vibrating transversely.

(*a*) Stretch a wire, *A*, on your monochord by means of a load, say 28 lbs., attached to the end of the wire which passes over the pulley. Alter the position of the movable bridge placed under this wire until the note emitted by the wire, when it is plucked, is in tune with your tuning fork or a certain length of the fixed wire. Note the length of the wire *A* which vibrates under these conditions.

Substitute a second wire, *B*, of the same material as *A* but of a different diameter. Ascertain where the movable bridge must be placed in order that the wire *B* when stretched by the same load may emit a note in tune with your fork or the same length of your fixed wire. Similarly record the length of the wire *B*.

Measure the diameters of wires *A* and *B*, as in Experiments 15 (*d*) and 15 (*e*) (Part I). Record thus:

Kind of Wire.	Stretching Load Used.	Length of Wire in Unison with Standard Note.	Diameter of Wire.

Show by calculation that

$$\frac{\text{Diameter of } A}{\text{Diameter of } B} = \frac{\text{Length of } B}{\text{Length of } A}$$

If any difficulty is experienced in telling when the notes are exactly in tune, the way to proceed is as follows: Keep the hand on the board, and it will be noticed that when the notes are very nearly in tune that "beats" will be felt. These become less and less frequent as the notes become more and more in tune until, when unison is perfect, they disappear.

63. Variation of Note with the Tension of a Transverse Vibrating String.

(*a*) Stretch a wire on your monochord by the smallest load that will give a clear note. Place the movable bridge at such a position that the wire is in tune with your tuning fork.

Increase the stretching load, and move the bridge until the note given by the wire is in tune with your fork. Record in every case the length of the wire which vibrates and the amount of the stretching load.

STRETCHING LOAD.	$\sqrt{\text{STRETCHING LOAD.}}$	LENGTH OF WIRE

Show by calculation that for a given note

$$\frac{\sqrt{\text{stretching weight (1)}}}{\sqrt{\text{stretching weight (2)}}} = \frac{\text{length (1)}}{\text{length (2)}},$$

and similarly for other wires.

The lengths for the same number of vibrations, and therefore the number of vibrations for equal lengths, are thus found to vary directly as the square roots of the stretching loads. The student should carefully consider and satisfy himself that this deduction is correct.

(*b*) Place a wire on the monochord and stretch it by a known weight. Find the length required to give a note in unison with the tuning fork of which the actual frequency is known. Weigh a measured length of the wire, and find the mass (m) of 1 cm. Express the stretching weight in dynes[1] (T), and hence test the following relationship.

$$\text{Number of vibrations per second} = \frac{1}{2} \cdot \frac{1}{l} \cdot \sqrt{\frac{T}{m}}.$$

[1] A dyne is the force which, acting upon a gram for one second, generates a velocity of one centimetre per second. The weight of 1 gram is g dynes, and of m grams is mg dynes. The value of g may be taken as 981 cm. per second. (See Part I., p. 162.)

64. Nodes in a String vibrating transversely.

(*a*) Place the bridge accurately at $\frac{1}{3}$ the length of the stretched wire, and along the longer portion place 12 or 16 small paper riders (Fig. 56) at short intervals. Throw the short length into vibration by a bow, and note that the paper riders are thrown off, except those at or near a point $\frac{2}{3}$ the length of the wire. Do the same with the bridge at $\frac{1}{4}$ the length, and observe the formation of two points of no vibration, that is, two *nodes*. Similar experiments should be done with the bridge at distances of $\frac{1}{5}$ and $\frac{1}{6}$ of the wire from one end.

FIG. 56.—A paper "rider" on a wire.

In Fig. 57 the letters n, n' mark where the riders will stay

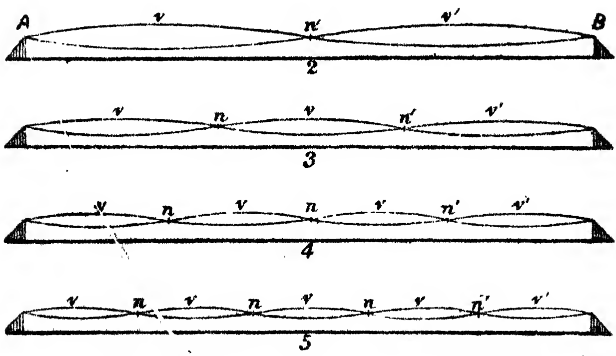


FIG. 57.—Nodes and antinodes in a string damped at different places, and set in transverse vibration.

on when a wire is vibrating in 2, 3, 4, and 5 parts, and the letters v, v' show where the wires will be thrown off.

CHAPTER IX.

SOUND: LONGITUDINAL VIBRATIONS.

65. Vibration of a Column of Air, and Determination of the Velocity of Sound.

(*a*) Nearly fill a tall cylinder with water and put into it a wide glass tube, open at both ends, and arrange a stand near to clamp the tube in any position (Fig. 58). Select a tuning fork the vibration number of which is known, and sound it either by bowing the prongs or by striking it on the table. Hold the sounding fork above the tube and raise or lower the tube in the water until the position at which the tube resounds or resonates most loudly is discovered. (The experiment must be done in a quiet room.) Clamp the tube in this position and carefully measure the distance from the level of the water to the open end of the tube. From these data calculate the velocity of sound in air, at the temperature of the room.

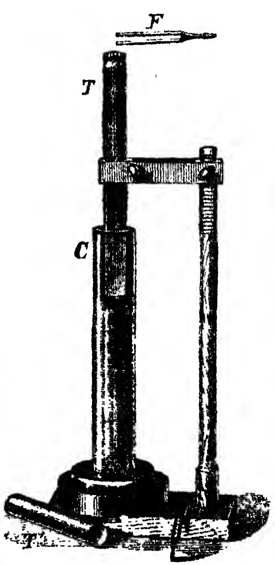


FIG. 58.—Determination of the velocity of sound in air by means of resonance.

The length of the column of air which is sounding its lowest note is one quarter of the wave-length of the note emitted by the fork; and the velocity of sound per second is equal to the number of

waves in a second multiplied by the length of one of them. Hence,

Velocity of sound per second in air at the temperature of the room	=	Vibration number of tuning fork	×	4 times the length of column of air.

(*b*) Repeat the last experiment, moving the tube up and down in the water, and observe there are several positions of maximum resonance. Measure the lengths of the column of air in each case and multiply by $\frac{4}{3}$, $\frac{4}{5}$, $\frac{4}{7}$, etc., according as there are 1, 2, 3, etc., nodes besides that at the surface of the water. This will give you the wave-length of the note, and you can proceed as before to obtain the velocity of sound.

(*c*) Fill the tube with carbon dioxide and again perform the experiment. Compare the velocity of sound in air with that in this gas. Also compare the square roots of their relative densities. You will find that

$$v_1 : v_2 = \sqrt{d_2} : \sqrt{d_1}.$$

(*d*) Assuming the velocity of sound already found, calculate the frequency of a tuning fork by finding the length of the column of the air which resonates to it.

66. Longitudinal Vibrations of Wires.

(*a*) Fasten a long thick copper wire to a drawing board (or other large board) by two holes, and fix the board upright at one side of the room. Stretch the wire by means of a hook at the opposite side, and rub it lightly with a resined cloth until it gives out a clear musical note. Find the length of wire of your monochord required to give the same note.

Alter the tension of the wire, and observe it has no effect on the note.

Fix also a wire of the same material but of different diameter, and make this vibrate; observe that it again gives the same note, hence the diameter has no effect upon the note.

By means of pliers tightly grip the wire at some point, and find the length of monochord wire which gives the new note. The frequency is found to be inversely proportional to length.

Use wires of different materials, and see that the frequency changes.

The velocity of sound in these wires is equal to twice the length of the vibrating wire × number of vibrations per second.

Use this relation to compare the velocity of sound in copper and iron.

67. Longitudinal Vibrations of Rods.

(*a*) Tightly clamp a long wooden rod at its middle point, or firmly hold it in the left hand. Take a piece of chamois leather, sprinkled with powdered resin, in the right hand. Beginning to rub near the left hand, draw the resined leather along the rod to its end. Continue the rubbing, and observe that a note is emitted by the rod.

The rod is set into *longitudinal vibration*. Since the rod is firmly grasped at its middle point, it is clear that at this place the rod is at rest or cannot be vibrating there. The ends of the rod are in most rapid vibration. The middle of the rod is a *node*. In this case

$$\text{wave length} = 2 \times \text{length of rod},$$

and, as in the case of the vibrating column of air (Exercise 65 (*a*)),

$$\begin{array}{c}\text{Velocity of sound}\\ \text{in the rod in}\\ \text{a second}\end{array} = \begin{array}{c}\text{Number of waves,}\\ \text{or vibrations in}\\ \text{a second}\end{array} \times \begin{array}{c}2 \times \text{length of}\\ \text{rod.}\end{array}$$

(*b*) To find the vibration number of the rod used in the preceding exercise, take the tuning fork, the vibration number of which is known, and find what length of the fixed wire of your monochord vibrates in unison with it. Cause the rod to sound exactly as in the preceding exercise, and similarly find what

length of the fixed wire vibrates in unison with it. Repeat with other rods. Record your results:

Longitudinal Vibration of Rods.

Kind of Rod.	Length of Wire which vibrates in Unison with Rod = A.	Length of Wire which vibrates in Unison with Tuning Fork = B.

Calculate the vibration number of the rod from the result obtained in Experiment 67 (b), thus

$$\frac{\text{vibration number of rod}}{\text{vibration number of fork}} = \frac{\text{length of wire } B}{\text{length of wire } A}.$$

(c) Using the relation discovered in Exercise 67 (a), calculate the velocity of sound in each of the rods.

Vibration Number of Rod.	Length of Rod.	Wave-Length of Note emitted by Rod.	Velocity of Sound in the Rod.

68. Comparison of Velocity of Sound in a Rod with that in Air by Dust Figures (Kundt's method).

(a) Clean and dry a long glass tube having a diameter of about an inch and a length of about six feet. You can do this by tying a plug of dry warm cotton-wool to the middle of a long piece of string, and, threading the tube upon the string, work

the plug of wool up and down. It will repay you to give some time to this process of drying and cleaning, as the success of the experiment depends upon the state of the inside of the tube. Put some perfectly dry lycopodium powder, or if you cannot get this, use some cork dust (obtained by rubbing a cork upon coarse glass paper), into the tube, and gently tilt the tube until the dust is arranged as a thin regular line along its whole length. Loosely close one end of the tube with a cork. Clamp one of your long wooden rods by its middle, and carefully insert one of its free ends into the glass tube, or fit it into the tube as shown in Fig. 59. It is better to first tack on a circular piece of cardboard rather smaller than the internal section of the glass tube. Rub the outside end of the clamped rod with the resined leather and move the cork or glass tube itself, until the dust figures produced are most distinct. The glass tube should rest horizontally in **V**-shaped supports.

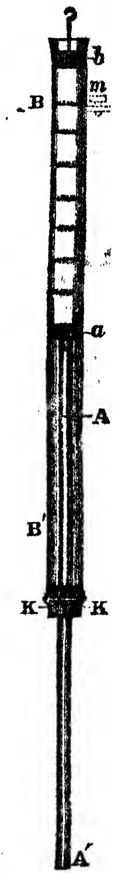


Fig. 59.—Tube and rod fitted for the production of Kundt's dust figures.

Measure the distance between n places where the dust is gathered, and divide by the number of spaces which occur in this distance (that is $n-1$). This will give you half the wave length of the sound wave in air. As you know, the length of the rod is itself half the wave length of the sound wave in the material of the rod, and consequently

$$\frac{\text{velocity of sound in air}}{\text{velocity of sound in rod}} = \frac{\text{half wave-length in air}}{\text{half wave-length in rod}}.$$

Use your observations to compare the velocities of sound in air and in the rod.

69. Interference of Vibrations.

(*a*) Gently cause a tuning fork to vibrate. Holding it vertically between the finger and thumb, bring it near the ear, and rotate it. Notice that in four positions the sound will cease entirely. The waves from the separate prongs when the fork is in the position of silence reach the ear in exactly opposite phases and produce silence.

FIG. 60.—Interference of sound waves.

(*b*) Obtain two similar wide-mouthed bottles of about 8 oz. capacity, and two pieces of glass about 2 inches by 2 inches. Hold a vibrating fork to the mouth of one of these bottles, and slide one piece of glass over the mouth until the air in the bottle resonates loudly to the fork. Fix the glass, by soft wax, in this position, and do the same with the second bottle.

Hold the fork above one of these bottles and slowly rotate it—in certain positions the resonance is almost *nil*. The different positions for this silence or minimum resonance should be observed.

(*c*) Fix the two bottles at right angles, and hold the vibrating fork horizontally (Fig. 60); move it slowly up and down and observe a position of silence; when this is found, cover the mouth of one bottle by a piece of card and observe the loud resonance of the other.

CHAPTER X.

PROPERTIES OF MAGNETS.

70. Lodestone as a Natural Magnet.

(*a*) Examine the piece of lodestone provided. Dip it into iron filings. Observe that the filings adhere in tufts to certain parts of the lodestone.

(*b*) Take a second piece of lodestone which has been roughly shaped so that the places where the filings adhered are now situated near its ends. Support the piece of lodestone by a silk fibre and hook as shown in Fig. 61, and prove that even if at first arranged in any other way, the piece of lodestone, after swinging for some time, eventually comes to rest along a certain line, and one end of the lodestone, which you can mark with chalk, always points in the same direction.

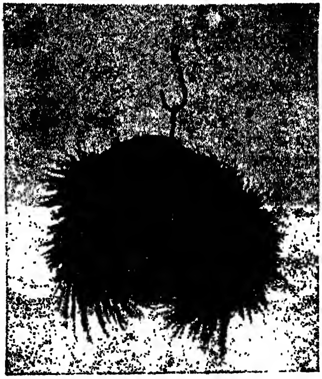


Fig. 61.—A piece of lodestone swinging freely.

(*c*) Leave the piece of lodestone of the last exercise suspended in its position of rest. Bring up the first piece of lodestone towards it in such a manner that one of the places where the filings adhered points at the end of the suspended piece. Observe what happens. Now point it at the other end of the suspended lodestone and again observe the result.

In one case *attraction* takes place, while in the other *repulsion* ensues.

71. Magnetic Attraction and Repulsion.

(*a*) Take a good-sized sewing needle and fix it on the table with a little soft wax. Using the piece of lodestone from the stirrup in the last experiment, and beginning at the point of the needle, rub the end of the lodestone along the length of the needle, and when you get to the eye, raise the lodestone and bring it again on to the point of the needle and repeat the stroking process. Do this 10 or 12 times.

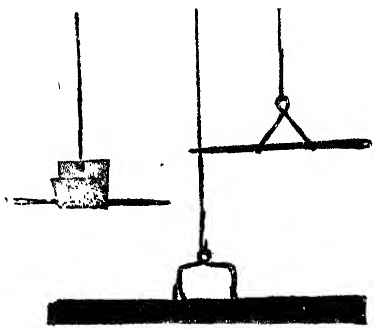


FIG. 62.—Stirrups for supporting magnets.

Examine the needle. It will now attract iron filings at its ends Support it in a tiny stirrup (Fig. 62), and see that it arranges itself as the shaped piece of lodestone did. Also notice that while the point is either attracted or repelled by the end of the shaped lodestone, the eye is repelled or attracted, that is, behaves in an exactly opposite manner.

> The needle has been made into a *magnet*, or has become *magnetized*. Most filings are attracted at its ends; and these places of greatest magnetic strength are known as the *poles* of the magnet.

(*b*) Examine the *artificial magnets* provided. Notice some are in the shape of *bars*, others in that of a *horse-shoe*.

Treat the bar magnet in the same way as the shaped lodestone.

(i.) Support it in a stirrup as in Fig. 62, and see that it arranges itself along the *same* line as the lodestone did.

(ii.) Dip both ends successively into iron filings. Notice and sketch the way in which the filings form a tuft. These ends are the poles. No filings adhere to the centre of the magnet.

(iii.) Support the magnetized needle as in Exercise 71 (*b*). Bring first one end of the bar magnet, and then the other, up to the point of the needle. Notice and record the result. Repeat, using the eye of the needle.

In every respect the artificial magnet has the same magnetic properties as the lodestone.

(*c*) Substituting the bar magnet for the shaped lodestone, magnetize another needle as in Exercise 71 (*a*).

Support the two magnetized needles, which you now have, each in a little stirrup. Allow them to swing freely and come to rest. On the ends of the two needles which point in the same direction stick a piece of paper, or mark them in some other convenient way.

Leave one needle in its stirrup and take the other out. Holding the needle in your hand, bring the marked end up to the marked end of the suspended needle. Notice repulsion. Bring the unmarked end of the needle in your hand up to the unmarked end of the suspended needle. Again notice repulsion.

Now bring the unmarked end of one against the marked end of the other. Notice attraction.

This teaches what is called the First Law of Magnetism, namely, *Like poles repel one another, and unlike poles attract one another.*

(*d*) Substitute a French wire nail for the needle in your hand in the last experiment. Notice when either end of the nail is brought up to the marked or unmarked end of the suspended magnetized needle, attraction ensues.

Since unmagnetized iron will attract both poles of a magnetic needle, the Exercises lead to an important conclusion, viz. *repulsion is the only sure test of permanent magnetization.*

72. How to Magnetize a piece of Steel.

In addition to the plan adopted in Exercise 71 (*a*), which is known as the method of *Single Touch*, there are other ways of magnetizing a piece of steel. One is called the method of *Separate or Divided Touch.*

(*a*) Straighten a piece of clock-spring. Fix it with wax upon the ends of two bar magnets, arranged as in Fig. 63. Now take two other bar magnets and hold one in each hand, inclined at about the angle shown in the illustration, to the piece of watch-spring. Draw the magnets away from one another, always keeping them inclined at the same angle to the watch-spring.

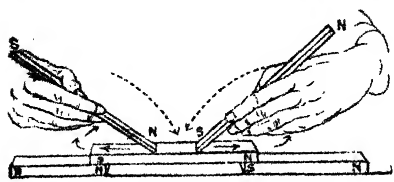


FIG. 63.—Separate or divided touch.

When the ends of the watch-spring are reached, bring the bar magnets back to their starting-point at the middle of the bar along the path indicated by the dotted line. When you have done this ten times, turn the piece of watch-spring over and repeat for another ten times on the side of the spring now on the top. Test the poles of the magnet by Exercise 71 (*c*).

73. Magnetic Meridian.

(*a*) Remove all magnets, also any masses of iron to a distance. Support a bar magnet in a paper stirrup, and see that it swings freely. Allow it to come to rest and then draw a chalk line on the table, marking the line along which the magnet arranges itself. One way of doing this is to make marks on the table immediately below the middle points of both ends of the magnet by the help of a plumb line, and then to join the marks by means of a straight edge. Or, you may draw a line accurately parallel to one of the long sides of the magnet.

(*b*) Freely support each of the magnets you have in order, viz. the shaped lodestone, the magnetized needles, and the horse-shoe magnet, above this line. The horse-shoe magnet is best supported by a thread. Notice that on coming to rest they all arrange themselves along the same line

The line along which a freely suspended magnet arranges itself is known as the *magnetic meridian*, and it can be at once *roughly* traced for any place by the simple experiment you have performed.

74. Accurate Determination of Magnetic Meridian.

(*a*) Using a mariner's compass[1] provided with sights, proceed as follows :

Look down one of the sight tubes (*t*, *t'* Fig. 64) and rotate the box until the sight needles can be seen in the middle of the

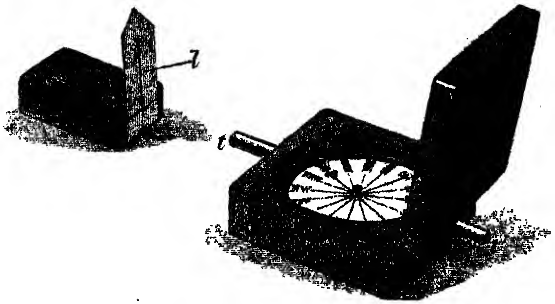


FIG. 64.—To find the magnetic meridian.

tubes. Move the supported piece of cardboard with the line *l* (Fig. 64) marked on it until this line lies on the same straight line as the index needles, and then make a mark on the table where the line *l* touches the table *a* (Fig. 65). Put the supported card in another position farther from the box, repeat the process, and mark a new place *b* (Fig. 65). The line joining *a* and *b* is the magnetic meridian. Permanently mark this line on your working bench ; it will be useful in future experiments.

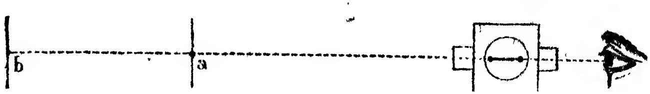


FIG. 65.—Marking the magnetic meridian.

[1] Full instructions for making this piece of apparatus will be found in *Practical Physics for Schools*, by Stewart & Gee, Vol. I., "Electricity and Magnetism," from which Figs. 64 and 65 are taken.

(*b*) Or, if a mariner's compass of the kind shown in Fig. 64 is not available, proceed as follows:—Attach two sewing needles to the ends of a magnetized knitting needle or of a bar magnet by means of soft wax, as shown in Fig. 66, with the needles in a vertical position, and so that their points travel just over the surface of the table. Use these points for "sights." When you have marked the meridian remove the magnet and turn it over, so that the face which was at first below is now on the top, using the eyes of the needles as "sights," and again determine the meridian. Take the mean position as an accurate determination. In this way you have corrected possible errors of the magnetic axis of the magnet and in the adjustment of the needles.

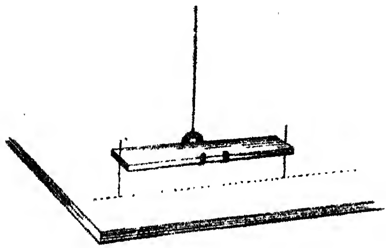


FIG. 66.—Simple method of determining the magnetic meridian.

75. Magnetic Declination.

The geographical meridian of a place is an imaginary circle round the earth, which passes through the north and south *geographical* poles, and through the place under consideration. The north and south *magnetic* poles of the earth do not coincide with the geographical poles, hence the magnetic meridians and the geographical meridians round the earth intersect one another. The angle which the two kinds of meridians through a given place make with one another is spoken of as the *declination* at that place.

(*a*) To determine the geographical meridian of a place from magnetic observations, first draw the magnetic meridian for the place, as in Exercise 74 (*b*). Refer to the Magnetic Chart (Fig. 67), and find the nearest place there given to that in which you

are performing the experiment. The numbers at the bottoms of the lines running from the top to the bottom of the chart

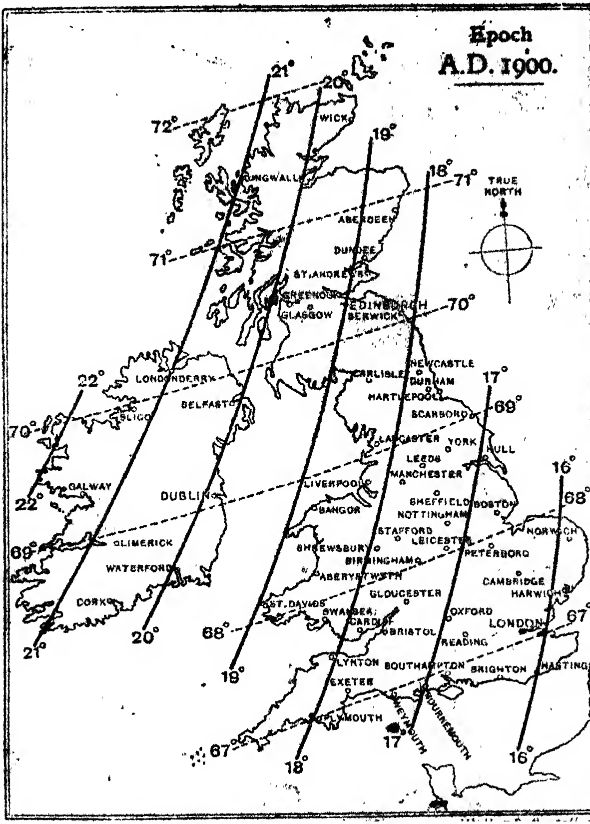


FIG. 67.—Magnetic Chart of the British Isles, showing the lines of equal declination and those of equal magnetic dip. (From *Elementary Lessons in Electricity and Magnetism*, by Prof. S. P. Thompson.)

show the magnetic declination in the British Isles. Mark the point of suspension of your magnetic needle on the magnetic

meridian you have traced, and at this point, using your protracter, draw a line intersecting your magnetic meridian at an angle equal to the magnetic declination for your locality. As all the magnetic declinations in the British Isles are west of true north, the line should be drawn to the east of your magnetic meridian. The line thus drawn represents the geographical meridian, which, if continued in both directions, round the earth, would pass through the north and south geographical poles.

76. Result of breaking a Magnet.

(*a*) Magnetize a piece of clock-spring. Find which end is repelled by the marked end of a suspended magnetic needle, and stick a piece of paper on this end. Convince yourself that the other end of the piece of clock-spring is attracted by the marked end of the suspended needle. Observe, too, that the middle of the piece of spring has no effect on the needle.

Break the piece of spring into halves, and examine each piece by bringing the ends of the pieces in turn up to the suspended needle. What was, before breaking, the middle part of the piece of spring is now found to affect the needle and to attract iron filings. Or, each piece is a perfect magnet.

By means of the suspended magnetized needle satisfy yourself that the other end of the half, which is marked, is repelled by the marked end of the needle, and that the other end of the half, which is unmarked, attracts the marked end of the needle.

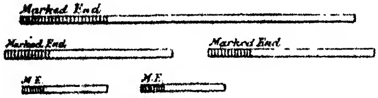


FIG. 68.—The results of breaking a bar-magnet.

Break one half into two equal parts. Show that each part is a perfect magnet. Also find how the poles are arranged. Record your results, and compare them with Fig. 68.

(*b*) Very nearly fill a small narrow test-tube with *steel* (not iron) filings, and close the tube with a well-fitting cork. By one of the methods already learnt, and using a large, strong magnet, magnetize the tube and its contents as if it were a bar of iron. Satisfy yourself that you have magnetized it by observing its

action on a magnetic needle. Now shake the filings out of the tube on to a sheet of paper; toss them about, and then replace them in the tube, and again test its magnetic condition with a magnetic needle. The tube and its contents no longer behave as a magnet.

77. Induction and Induced Magnetism.

(*a*) Take a strip of galvanized iron, and, adopting the method of single touch (Ex. 71 (*a*)), endeavour to magnetize it. After rubbing 10 or 12 times test it with iron filings and with a magnetic needle. It has not been magnetized.

(*b*) Take a bar magnet in your left hand and with the right hold the piece of galvanized iron in contact with the bar magnet and bring the galvanized iron (while it is still touching the bar magnet) into contact with some iron filings. The iron filings adhere to the galvanized iron, or, while it is in contact with the bar magnet the galvanized iron is itself a magnet.

(*c*) (i.) Suspend a long unmagnetized needle. Bring near to it the north-seeking pole of a magnet. (Fig. 69). The attraction which ensues suggests that the end of the needle, *a*, nearest to the north-seeking pole of the magnet is a south-seeking pole. What about the other end?

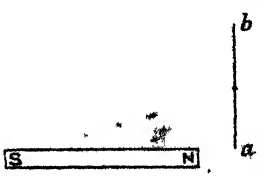


FIG. 69 – To illustrate Ex. 77 (*c*)

(ii.) Arrange the needle and magnet as shown in Fig. 70, and test the polarity of the more distant end, *b*, by means of a

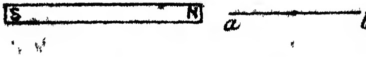


FIG. 70.—To illustrate Exercise 77 (*c*).

compass needle. Repulsion shows that it is a north-seeking pole.

(iii.) Take away the bar magnet and the end *b* will attract either *n* or *s*, and hence the magnetization of *ab* was only temporary.

(*d*) Arrange several pieces of soft iron on a piece of card-board, and bring up a bar magnet as in Fig. 71. Test the

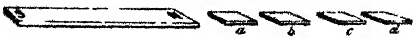


FIG. 71.—To illustrate Exercise 77 (*d*)

polarity of the more distant pieces by means of a very short magnet suspended from a silk fibre.

(*e*) Attach as many French wire nails in a chain to the end of a bar magnet as you can. Examine the polarity of the end

FIG. 72.—Exercise 77 (*e*).

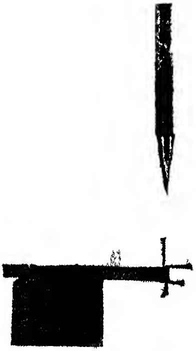


FIG. 73.—Exercise 77 (*e*).

nail as before. Arrange a second magnet as shown in Figs. 72 and 73, and examine the effects in each case.

78. Lines of Force.

(*a*) Place a bar magnet on the table, and over it place a thin sheet of cardboard. Sprinkle fine iron filings on to the card, either from a fine pepper castor or from a fine muslin bag.

Gently tap the sheet of cardboard, when the filings will be seen

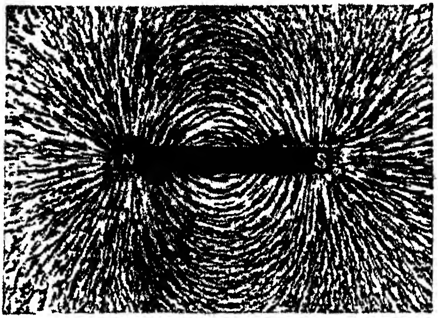


FIG. 74.—Lines of force round a bar-magnet

to arrange themselves along definite lines, which are called *Lines of Force*.

(*b*) Substitute a sheet of glass for the cardboard, and repeat the experiment. Make a sketch of the figure obtained in your note-book.

(*c*) Similarly obtain the lines of force for a horse-shoe magnet, and for the following combinations.

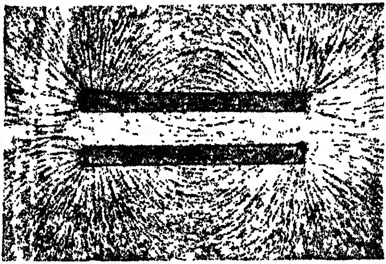


FIG. 75.—Lines of force around two bar magnets having like poles adjacent.

(i.) Two bar magnets in the same straight line, with opposite poles 2 cm. apart.

(ii.) Same arrangement, only similar poles, 2 cm. apart.

(iii.) Two bar magnets arranged parallel with opposite poles near one another.

(iv.) Two bar magnets arranged parallel with similar poles near one another (Fig. 75).

(v.) One pole of a bar magnet held vertically under the piece of cardboard.

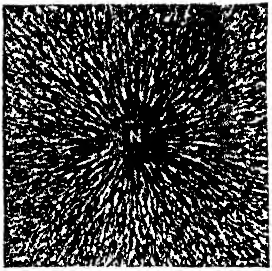


FIG. 76.—Lines of force around a single magnetic pole.

(*d*) Make a very short magnetic needle. You can do this by magnetizing a knitting needle, and carefully breaking off a piece from it. Support this short piece, which, as you know, is a perfect magnet, by a fibre of unspun silk. It is convenient to attach the piece of silk by the aid of a piece of soft wax. Call this freely suspended short magnet your *exploring magnet*.

Re-obtain the lines of force for a single magnet as in Exercise 78 (*a*). Hold your exploring magnet over the piece of cardboard, and just above the iron filings. Notice that the exploring magnet arranges itself along the line of force, passing through its point of suspension. Vary the position of your exploring magnet and notice the same thing is always true.

79. Magnetic Dip.

Though we have assumed in all the previous Exercises that a small magnet freely suspended hangs more or less horizontally, the student may have noticed that this is not exactly so.

(*a*) Take a knitting needle and support it by a fibre or two of unspun silk, attached by soft wax, so that the needle is horizontal. Now, holding it carefully so as not to break the silk, magnetize it by the method of single touch. Allow it to again hang freely. It is no longer horizontal. One end *dips* down. By means of a compass needle ascertain which pole is dipping, and record your result.

A needle which is free to move on a vertical plane, but fixed as regards movement in a horizontal plane, is called a *dipping needle*.

(*b*) Either use the dipping needle provided, or make a simple form yourself.[1] To do this select an unmagnetized knitting-needle about 12 cms. long. Construct an axle for the needle in the following manner: Hold two short pieces of copper wire on opposite sides of and at right angles to the length of the needle. Twist the ends of the wires together on each side so as to grip the needle tightly, and carefully straighten the twists (Fig. 77). Make the wire surfaces as smooth as possible by heating in a gas-flame and applying sealing wax, shaking off the excess of wax while still fluid. Apply a spot of sealing wax so as to rigidly connect the axle to the needle. Make a support for the needle by cutting two rectangular pieces of sheet brass or copper (7 cms. × 1 cm.), rigidly connect them together at the base with their short edges horizontal and 1 cm. apart, and fix them to a suitable base-board (or a support may be made with two pieces of glass rod fixed horizontally and 1 cm. apart). Attach a circular scale of 90° to one of the supports (Fig. 78). See whether the needle is truly balanced by supporting it by its axle on the knife edges; if necessary,

FIG. 77.—Support for a simple form of dipping needle.

[1] This easily-constructed form of dip needle was designed by Mr. H. E. Hadley, B.Sc.

adjust the position of the axle by slightly warming the sealing-wax joint and moving the axle along the needle. Carefully magnetize the needle. Place it on the knife edges with its axle coinciding with the centre of the circular scale.

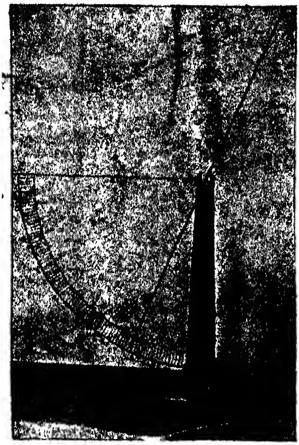


FIG. 78.—A simple form of dipping needle.

80. Determination of the Angle of Dip.

To make an accurate measurement of the angle of dip you must be sure of one or two things.

(*a*) *The needle must move in the plane of the magnetic meridian.*

One plan to ensure this is as follows: Carefully draw the magnetic meridian by Exercise 74, and then arrange the needle parallel to this line.

A better way, and the plan generally adopted, is to first rotate the needle until it stands quite vertical, pointing to the zero division of the scale. Turn the plane in which the needle is free to move through exactly 90°, thus making this plane to exactly coincide with the meridian.

(*b*) *The magnetic axis of the needle must coincide with that of figure of the instrument.*

To eliminate any error due to this not being so the needle is so arranged that it can be lifted off and used round the other way, that is, with the face previously behind facing the front of the instrument. Do this and take the mean of the readings.

(*c*) *The centre of gravity of the needle may not coincide with the point of suspension.*

To avoid error from this cause, after the first observation of dip has been taken the needle must be taken out, demagnetized

and then remagnetized in such a way that what was originally the south pole is now the north.

(*d*) Make several measurements of the angle of dip. From the chart in Fig. 67 make a table showing the magnetic declination and dip at ten of the places represented.

81. Magnetization of Soft Iron by the Inductive Action of the Earth's Magnetism.

(*a*) Arrange vertically, in the magnetic meridian, a large sheet of cardboard on which you have drawn two lines, viz.: a horizontal line and one inclined to it at an angle equal to the angle of dip determined in the last experiment. Place the rod of soft iron, a long strip of galvanized iron will do best, along the inclined line, and smartly rap it a few times with a mallet while it is held in position.

(i.) Still holding the soft iron in this position, test its polarity by a suspended magnetic needle. The strip of soft iron will be found to be a magnet. The end towards the north is a north-seeking pole.

(ii.) Now hold the strip of galvanized iron at right angles to the meridian, strike the strip with a mallet and again test its polarity. You have demagnetized it.

(iii.) Reversing the ends of the strip of galvanized iron, repeat (i.) and (ii.).

(iv.) Holding the strip horizontally, and in the magnetic meridian, repeat (i.) and (ii.).

(v.) Holding the strip vertically, again repeat (i.) and (ii.).

(vi.) Compare the strength of the polarity in (i.), (iii.), (iv.), and (v.) by bringing the strip in each case near to a magnetometer needle and reading the deflection. Take care that the strip is carried very carefully, so as not to shake it or make it vibrate, and see that it is arranged every time at the same distance from the needle.

CHAPTER XI.

MAGNETIC MEASUREMENTS.

By the *magnetic moment* of a magnet is meant the product of the strength of one of the poles into the distance between the poles. If we express the strength of either pole by m, and the distance between the poles by l, we can write

$$\text{Magnetic moment} = ml.$$

To obtain a correct idea of the strength of a magnet, it is necessary to measure the value of this product for the magnet; or, if you only wish to compare the strength of one magnet with that of another, it is sufficient to compare the values of their magnetic moments.

82. Construction of a Magnetometer.[1]

(*a*) Select a strong tumbler, and fit it with a thin cork such as is used for pickle bottles. Through it pass stout brass wires, as shown in the illustration (Fig. 79), one, the shortest, passes through the centre of the cork, the other is fixed at equal distances from the centre, and on to the horizontal part, which is inside the tumbler when the cork is put into position, attach a circular card graduated into intervals of ten degrees. Magnetize a thin narrow strip of straightened watch spring, and fasten it with bees'-wax on to a piece of stout paper. Cut the paper into the shape of a narrow magnet, pointed at each end. Hang, by means of a silk fibre, the magnet and its attached paper (seen

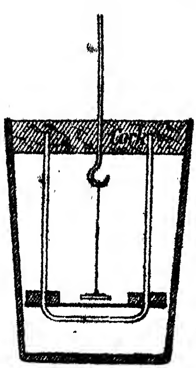


FIG. 79.—A simple magnetometer.

[1] The simple and effective form of instrument here described was designed by Dr. Buchanan, Gordon's College, Aberdeen.

end-on in Fig. 79) to the centrally-fixed brass wire, at such a distance that the magnet swings just over the card. You now have a very effective magnetometer which can, if the other apparatus is not available, be used in the following exercises.

83. Comparison of the Magnetic Moments of two Magnets

First Method.

(*a*) Arrange the magnetometer box[1] and scale in the manner which Fig. 80 makes clear. Notice that the magnetometer consists of a compass box, with a small magnet carefully pivoted

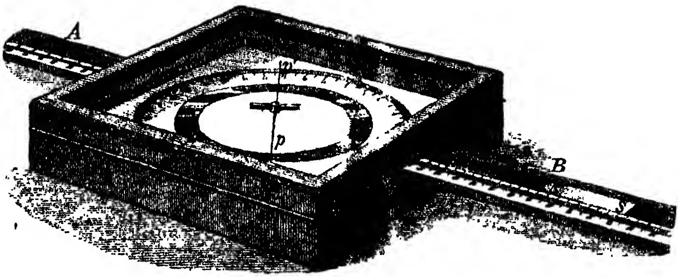


FIG. 80.—A deflection magnetometer.

at its centre. A pointer is arranged at right angles to the magnet, and is long enough to move over the graduated circle. The two graduated arms *A* and *B* must be at right angles to the magnetic meridian, and a magnet, *NS*, is placed as shown. Record its position on the scale. The needle is deflected from its position of rest. Observe and record the angle of deflection produced. Replace the first magnet by the second, taking care that its centre is placed in exactly the same position on the scale as the centre of the first magnet. Again observe the angle of deflection.

[1] Or you can use the magnetometer you have made and an ordinary metre scale.

Record your results as follows:

		Distance of Centre of Magnet.	Deflection with Magnet on Left-Hand Side.	Right-Hand Side.	Mean Deflection.	Tangent of Mean Deflection.
Expt. 1	(1)					
	(2)					
Expt. 2	(1)					
	(2)					

Results of Expt. 1 = ...

" " 2 = ...

Repeat the experiment once or twice, taking different positions for the magnets, *e.g.* (1) put them at equal distances on the other arm of the instrument and (2) reverse the poles. Then the magnetic moments are to one another in the proportion of the tangents of the angles of deflection,[1] or

$$\frac{\text{Magnetic moment of magnet 1}}{\text{Magnetic moment of magnet 2}} = \frac{\text{Tangent of 1st deflection}}{\text{Tangent of 2nd deflection}}.$$

Second Method.

(*b*) Arrange the apparatus used in the last Exercise, in the manner there described. Place the two magnets (M_1 and M_2) of unequal strengths, the magnetic moments of which it is wished to compare, one on each side of the graduated arms A and B, with similar poles pointing towards the needle. Vary the distance of one of them from the magnet until no deflection of the needle takes place, that is, until the pointer is exactly over the zero readings of the scale. Read off the distances, d_1 and d_2, from the centre of the magnets to the centre of the needle, and record the result. Vary the distance of the fixed magnet,

[1] Look up the value of the tangent of the angle of deflection from the table on p. 165.

and again find where the other must be placed to exactly counteract the effect of the first magnet on the needle. Again record the distances. Repeat the experiment with reversed poles for the distances employed before.

Magnet M_1.		Magnet M_2.		
Distance from Compass $=d_1$.	Cube of Distance from Compass $=d_1^3$.	Distance from Compass $=d_2$.	Cube of Distance from Compass $=d_2^3$.	$\frac{d_1^3}{d_2^3}$.

Find the values of the ratios in column 5, and observe that they are constant. Or, expressed in words, the forces exerted by the magnets, M_1 and M_2, tending to produce a turning of the compass needle, are inversely proportional to the cubes of their distances from the needle.

84. Comparison of the Horizontal Components of the Total Magnetic Force in any two Places.

(*a*) Suspend a magnet in a light stirrup, as in *s*, Fig. 81. Support it by two or three silk fibres from a hook, as at *h*. The hook is conveniently attached to a cap, *c*, which

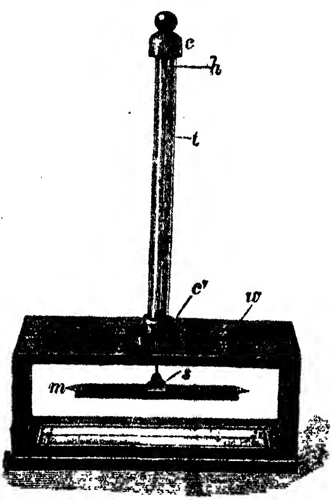


Fig. 81.—A vibration magnetometer.

fits a glass tube, t, which slips into a collar, c', in the roof of a box in which the magnet swings. Gum pieces of paper to the magnet to act as indexes, as m in Fig. 81. Have a line ii' on the floor of the box, which is preferably made from a piece of looking-glass. Allow the magnet to swing. Find the time taken to complete ten swings. Calculate the time, t_1, of one swing from the mean of several observations.

Repeat the observation in another locality, or in a magnetic field of different intensity, and ascertain the time t_2 of one swing. Then

$$\frac{\text{Horizontal component of 1st field}}{\text{Horizontal component of 2nd field}} = \frac{t_2^2}{t_1^2}.$$

If a vibration magnetometer like that shown in Fig. 81 is not available, the magnet and needles of Exercise 77 can be used. Any draughts should be screened off with an exercise book. A piece of cardboard with a peep-hole can be used to keep the 'line of sight' correct.

85. Distribution of Magnetism in a Bar Magnet.

(*a*) Support the bar magnet vertically in a wooden universal joint. Take a small, freely-suspended magnetic needle, like the exploring magnet in Expt. 78 (*d*), but which has been weighted by tying a piece of zinc rod of the same length to it, so as to diminish the number of vibrations. Bring it near to the bar magnet, at a short distance from one of its ends (Fig. 82.) Allow it to oscillate, and count the number of oscillations in a given time, say 30 seconds, or 1 minute. Repeat this at different distances from one end to the centre of the magnet, taking great care that the swinging needle is in every case at exactly the same horizontal distance from the bar magnet, recording

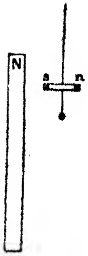


FIG. 82.

the number of oscillations for the time observed for each position.

Position.	Distance from End of Bar Magnet.	Number of Oscillations.	
		(*a*) In thirty seconds.	(*b*) In one minute.
A	...... cm.	......	......
B			
C			
D			

(*b*) Find the number of oscillations when the small magnet oscillates under the influence of the horizontal component of the earth's magnetism alone, that is, when it is at a distance from all artificial magnets or other disturbing influences.

Arrange your results thus :

Position.	Number of Oscillations, *N*.	Square of Number of Oscillations, N^2.	Number of Oscillations due to Earth, *E*.	Square of Number of Oscillations due to Earth, E^2	N^2+E^2.
A					
B					
C					
D					

(*c*) To map the results, draw an elongated rectangle to represent the bar magnet under examination. Mark off, to scale, the various positions recorded in the table of results along the rectangle as shown. At these points erect perpendiculars of heights proportional to the results obtained in column 6 above, and join

in by a smooth curve. This curve will serve to indicate how the strength of the magnetism falls off towards the centre of the magnet.

Notice that the result obtained at the position *F* (Fig. 83) is the same as that when the needle oscillates under the influence of the earth alone.

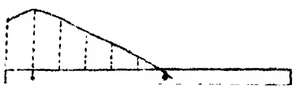


FIG. 83.—Map showing distribution of magnetism in a bar magnet.

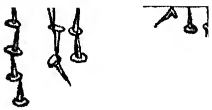


FIG. 84.

(*d*) Imitate the results by adding wire nails to a bar magnet as in Fig. 84.

CHAPTER XII.

DEVELOPMENT AND TESTS OF ELECTRIFICATION.

86. Development of Electrification by Friction.

(*a*) Arrange a variety of small light fragments, such as pieces of paper, bran, saw-dust, in a heap upon the table. Vigorously rub a rod of glass with a piece of dry silk[1] and hold it over the light fragments. Observe how they are attracted by the rod.

(*b*) Repeat the last experiment, using

(*a*) Rod of sealing wax and flannel.
(*b*) Rod of ebonite and a cat's skin.
(*c*) Sheet of brown paper and a clothes brush.

[1] To obtain satisfactory results the rods and rubbers should be quite dry and warm. This can be ensured by placing them on sand contained in a baker's tray supported on a couple of tripod stands and warmed by a Bunsen burner or two. The tray should be covered with a piece of sheet iron bent into the form of an arch.

87. Electrical Attraction and Repulsion.

(*a*) Make a stirrup out of stout copper-wire. Hang it from the ring of your retort stand by means of a thread or ribbon. Balance a round ruler in the stirrup. As in Experiments 86 (*a*) and 86 (*b*) electrify one of your rods by rubbing and bring it near to the balanced ruler. Notice attraction.

(*b*) Substitute other heavy rods for the ruler and observe that all are attracted by the electrified body. Vary the experiment by balancing the rubbed, and consequently electrified, body on the stirrup, and holding the rods, which were previously balanced, in your hand, bring them up to the rod on the stirrup. Again attraction takes place.

> You are consequently justified in asserting that not only does an electrified body attract unelectrified bodies, but also that unelectrified bodies attract electrified bodies.

(*c*) Repeat Exercise —, and observe that after the light particles have been attracted by, and touch, the electrified rod, they are immediately repelled.

Or, support two pith-balls by two cotton threads to a support with a varnished glass leg, as in Fig. 85. Bring the electrified rod near the balls. They are attracted by, and touch, the rod. This is followed by repulsion, and afterwards it will be observed that the balls repel one another and stand apart.

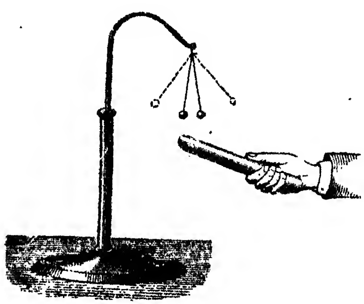


FIG. 85.—Electrical repulsion.

88. Two kinds of Electrification.

(*a*) Rub a piece of glass tube with the piece of dry silk, and support it on the hanging stirrup. Then rub a piece of sealing wax with flannel and bring the rod of sealing wax near the glass

tube. Notice *attraction.* Record the fact that glass rubbed with silk is attracted by sealing wax rubbed with flannel.

Repeat the experiment, first rubbing and supporting the sealing wax, and then approaching the rubbed glass tube. Notice the same result.

(*b*) Support one piece of glass tube which has been rubbed with the silk rubber (in this case it is advantageous to hang the stirrup by a silk thread) and bring up a second glass tube which has been similarly treated. Notice *repulsion.* Record the fact that glass rubbed with silk is repelled by other glass similarly treated.

Repeat the last experiment, using two sticks of sealing wax and a flannel rubber. Record the result.

(*c*) Also experiment with :

(i.) Two pieces of ebonite rubbed with fur.

(ii.) Two pieces of roll sulphur rubbed with flannel.

(iii.) A piece of glass rubbed with silk and a piece of ebonite rubbed with fur.

You are thus led to the conclusion that there are two kinds of electrification, viz. that generated on glass by rubbing it with silk, and that on sealing wax by rubbing it with flannel. The former is always spoken of as *positive* (+), and the latter as *negative* (−). What is called the *First Law of Electrification* follows from the experiments you have now performed. This law can be stated by saying,

Like kinds of electrification repel one another.
Unlike „ „ attract „

(*d*) Support a single pith-ball by a silk thread to a support with a varnished glass leg. Bring a glass rod which has been rubbed with silk in contact with the ball. After the ball has been repelled, as you now know, it is positively charged.

(*e*) Using two *pith-ball pendulums*, as the arrangement in the last exercise is called, one charged +ly and the other −ly,

test the nature of the electrification generated on the rubbed body in each of the following cases :

(i.)	Sulphur	rubbed with	fur,
(ii.)	"	"	flannel,
(iii.)	Ebonite	"	silk,
(iv.)	"	"	fur,
(v.)	Glass	"	flannel,
(vi.)	Amber	"	flannel,

and other things which are convenient.

89. Equal and Opposite Charges.

Equal amounts of the opposite kinds of Electrification are generated when two things are rubbed together.

(*a*) Make a flannel cap to just fit the end of a stout rod of sealing wax or other convenient substance. Attach a silk thread to the flannel cap. See that both rod and cap are dry and warm. Have a positively charged pith-ball pendulum near. Rotate the flannel cap once or twice by pulling the piece of silk which has been previously wound round it.

(i.) Holding the cap by the silk thread, bring it near the +ly charged ball. Notice repulsion. The cap is therefore +ly charged.

(ii.) Touch the pith ball with your finger, and then charge it negatively by means of a piece of sealing wax rubbed with flannel. Bring near it the end of the rod on which the flannel cap has been rubbed. Again notice repulsion. The rod was therefore −ly charged by the flannel cap.

(iii.) Put on the cap again and repeat the rubbing. Do not take off the cap, but bring both up to an uncharged pith ball. There is neither attraction nor repulsion.

90. Construction and Use of an Electroscope.

(*a*) Clean and dry a glass flask and fit it with a cork. Bore a half-inch hole through the cork. Solder a penny-piece or a disc of metal to one end of a straight brass wire 7 inches

long. Drill a hole in the edge of the disc. Surround the wire about 2 inches below the disc with shellac so as to fit the hole in the cork. Solder a piece of thin sheet brass about $\frac{1}{4}$ inch long to the lower end of the wire. Cut two strips of Dutch metal or aluminum leaf $\frac{1}{2}$ an inch wide. Slightly moisten the brass strip on each side with weak gum and take up the leaves. Shade from air currents and place in the flask.

(*b*) Or,[1] take a common thick glass tumbler and fit it with a cork. Procure a rod of good ebonite about 12 cms. long and 0·6 cm. in diameter to serve as the insulator. Bend the ebonite rod into a U-shaped form, one branch being not quite half as long as the other. The bending may be done by softening the ebonite in the flame of a laboratory burner or by keeping it for half an hour in boiling water. Firmly tie a stiff brass wire about 2 mm. diameter to the short branch of the bent ebonite rod with waxed thread, so that the wire is parallel to the longer branch of the rod. The lower end of this wire, bent at right angles and flattened sideways, carries the leaves, which may be of gold, Dutch-metal or aluminium, and are attached by gum. Solder the end of a piece of brass tube, 1 cm. long and of a diameter which will allow it to fit tightly on to the upper end of the brass wire, to a disc of tin-plate 8 cms. in diameter. The edge of the disc is turned over to avoid sharp edges. Bore two holes in the cork—one hole in the centre through which the brass wire passes without contact, the other at a suitable distance from the centre; and through the second hole the upper end of the ebonite rod is firmly inserted.

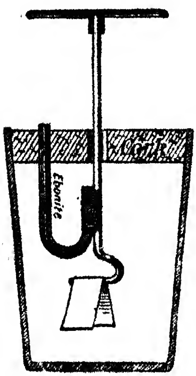


FIG. 80.—An electroscope.

A *proof plane* is required for use with an Electroscope. One can be constructed as follows:—

(*a*) Carefully clean a piece of glass rod about 10 inches long,

[1] This simple electroscope was designed by Dr. Buchanan, Gordon's College, Aberdeen, with whose permission it is here inserted.

the sharp edges of which have been first removed with emery paper or with a file. Dry and warm the glass. Then coat it with shellac varnish.[1] Fix a two-inch disc of tin, or of cardboard covered with tinfoil, to the end of the strip.

(*d*) To make an insulating stand,[2] procure a wooden disc about 11 cms. in diameter. Into this insert three legs of ebonite until they project vertically about 3 cms. from the surface of the disc. With the legs resting on the table, the disc forms a support for such a body as a tin can. If placed in an inverted position with the legs in the air, the extremities of the legs make a stable support for such a form as a sphere.

In charging the electroscope it is desirable to make a rule of bringing small charges only to the disc.

(*e*) Draw your proof plane along an electrified rod (or other body) and then transfer the small charge which collects on the proof plane to the disc of the electroscope. If necessary, repeat this process until the leaves diverge sufficiently. Another plan for charging an electroscope is given on p. 117.

91. Conductors and Insulators.

(*a*) Rub a brass tube held in the hand with a piece of dry silk. Bring it near to the cap of the electroscope. There is no divergence of the leaves.

Procure a piece of brass to which a varnished glass handle has been attached, and holding the rod by the glass handle, flick the brass with the silk, or with a cat's skin. Now, quickly bring the brass in contact with the cap of the electroscope. Notice the divergence of the leaves.

Try and think what causes the difference between this result and the former one.

(*b*) Cause the leaves of an electroscope to widely diverge by means of small positive changes from a proof plane. Touch the disc of the electroscope in succession with pieces of glass, sealing wax, solid paraffin, ebonite, and metal rod.

[1] Shellac varnish is made by dissolving flake shellac in methylated spirit.

[2] Dr. Buchanan, Gordon's College, Aberdeen.

Charge the electroscope again and touch the disc with the finger. Record your results.

(*c*) Arrange the electroscope with a long piece of wire attached, on the end of which is a metal knob, as in Fig. 87.

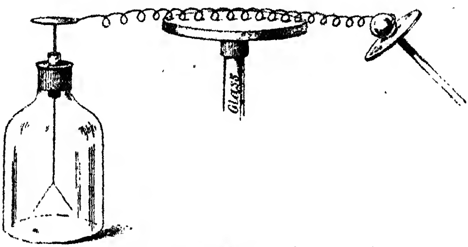


FIG. 87.—To illustrate electric conduction.

The wire rests on an insulating stand. Bring an electrified proof plane in contact with the metal knob. The leaves diverge, showing that the metal wire conducts the electric charge.

Repeat the experiment, using in succession, (*a*) cotton, (*b*) dry silk, (*c*) wet silk.

(*d*) Break the coil of wire on the insulating stand, and between the ends so formed place pieces of different substances, *e.g.* (*a*) lump of solid paraffin, (*b*) sealing wax, (*c*) dry wood (*d*) piece of porcelain and other things. Be sure that the wires are well joined to the block of material.

Make a table, dividing the things you are able to try into conductors and non-conductors or insulators.

CONDUCTORS.	NON-CONDUCTORS OR INSULATORS.

CHAPTER XIII.

ELECTRIC INDUCTION AND DENSITY.

92. Induction.

(*a*) Arrange a dry lath on an insulating stool in such a way that one of its ends is above the disc of an electroscope. Without touching the lath bring over the other end of it a positively charged glass rod. Notice the divergence of the leaves. Remove the rod and the leaves again collapse.

Repeat the exercise substituting a piece of sealing wax rubbed with flannel for the glass rubbed with silk.

(*b*) For the lath on the insulating stand substitute an insulated metal cylinder, or a wooden cylinder with rounded ends, coated with tinfoil or blacklead. By means of a copper wire, supported by an insulating handle, put one end of the

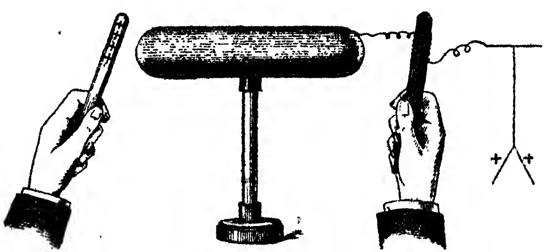


FIG. 88.—An electrified body is able to induce charges in bodies near it.

cylinder in connection with the disc of the electroscope (Fig. 88). Bring a positively charged glass rod near to, but not touching the other end of the cylinder. Hold the rod in this position and remove the connecting wire. The leaves remain diverging.

Test the kind of electrification causing the leaves to diverge. Charge the proof plane positively by bringing it into contact with a glass rod rubbed with silk. Bring the proof plane near

the cap of the electroscope. An increased divergence takes place showing that the leaves were positively charged.

Now test the cylinder. Discharge the electroscope by touching the cap with the finger. Recharge it negatively by means of a proof plane which has touched a rod of sealing wax rubbed with flannel. Holding the rod in position as before, test the near end of the cylinder with the proof plane. Transfer the proof plane to the cap of the electroscope. Notice the increased divergence. The cylinder was evidently charged with negative electricity.

(*c*) Bring a positively charged rod near one end of the insulated cylinder. Touch the end of the cylinder nearest to the rod with a proof plane and test the kind of electrification there. Discharge the proof plane and test the other end of the cylinder.

(*d*) Vary the experiment by placing two insulated spheres. (Wooden spheres coated with blacklead are very suitable, or knobs from a metal bedstead may be used) in contact; and while still holding an electrified rod near, but not touching one of them, separate the two spheres and test the kind of their electrification.

By these experiments it is established that when an electrified body acts by induction, or inductively, as this action at a distance is called, on an unelectrified body near it, it attracts the opposite kind of electrification to the end of the uncharged conductor near it and repels the same kind of electrification to the end remote from it.

(*e*) Bring a charged rod near to an insulated and uncharged metal cylinder. While the charged rod is near the cylinder, touch any part of the cylinder with the finger. Then remove the rod and test, by means of your proof plane, the kind of electrification on the cylinder.

It will be found to be of an opposite kind to that of the charged rod. When the cylinder was touched the charge of the same kind of electrification as that on the charged rod was repelled by the rod, through the body, to the earth. This charge is called *free*. The electrification

of the opposite kind to that on the rod was attracted to the part of the cylinder near the rod. This charge is called *bound*.

(*f*) Cause a charged rod to approach towards the disc of an electroscope (Fig. 89). Notice the divergence of the leaves. Still holding the rod in the same position, touch the cap of the electroscope. The leaves completely collapse. Remove, first the finger from the disc of the electroscope, and second, the rod from the neighbourhood of the electroscope. The leaves again diverge and remain divergent. Test the electrification of the leaves and convince yourself that the charge is of the opposite kind to that on the rod.

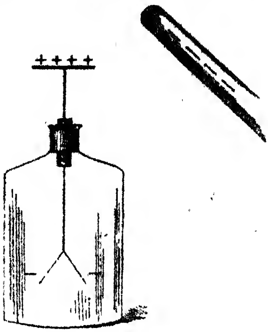


FIG. 89.—First step in charging an electroscope by induction.

Draw a series of diagrams showing the condition of electrification of the rod and parts of the electroscope during each of the stages of this experiment.

93. Phenomena of a Hollow Conductor.

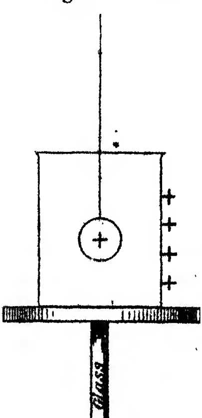


FIG. 90.—Exercise with a hollow conductor.

(*a*) Take your copper calorimeter or any metal canister and see that it is clean and dry. Place it upon an insulating stand. By means of a copper wire connect the outside of the canister with the disc of the electroscope. Tie a dry silk ribbon to a metal ball. Hold the ball by the ribbon and charge it positively by placing it in contact with a glass rod rubbed with silk. Now lower it into the canister, but do not let it come into contact with its sides (Fig. 90). Observe the divergence of the leaves of the electroscope. Still holding

it by the ribbon, remove the ball and notice that the leaves collapse again.

Bearing in mind what you have learnt about induction, draw a diagram in your note-book explaining these phenomena.

(*b*) Repeat Exercise 93 (*a*) and when with the ball lowered inside the canister the leaves are diverging, knock away the wire which connects the canister and electroscope. The leaves remain divergent. Test the kind of electrification on the leaves.

(*c*) Again repeat the last experiment, but this time (i.) Introduce the ball as before without touching the inside. (ii.) Touch the tin can with the finger. (iii.) Remove the ball without touching the can. Test the kind of electrification on the leaves. It is different from the last experiment.

(*d*) Place the canister on the insulating stand and bring a charged metal ball suspended as before in contact with the inside of the canister. Repeat this process half-a-dozen times. Try and charge your proof plane by stroking the sides and bottom of the inside of the canister (Fig. 91), testing your success by bringing the proof plane in contact with the cap of the electroscope. No charge is obtained. Similarly try the outside of the canister. The proof plane is easily charged.

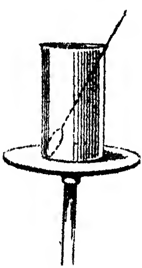


FIG. 91.—There is no electric charge inside a hollow conductor.

(*e*) Repeat the last exercise, this time strongly charging the canister by connecting the inside of it with the prime conductor of a frictional electrical machine. Again try to charge your plane from the inside of the canister. It is still impossible.

> There is no charge inside a hollow conductor, however it may have been electrified. The charge always collects on the outside; hence there is no electric force inside a hollow conductor.

(*e*) The principle of Exercise 39 may be proved in another

way. Mount a disc of sealing wax or ebonite on an insulating handle and also a piece of flannel or cat's skin glued to a board. Holding both by the handles rub them together and put (1) the ebonite or sealing wax into a hollow conductor arranged on an insulating stand and in connection, by means of a copper wire, with an electroscope; (2) treat the flannel or cat's skin in the same way; (3) put both the body rubbed and the rubber together into the hollow conductor. Record the results.

94. Construction of an Electrophorus.

(*a*) Cut a piece of cardboard 5 in. square. Round its corners and smooth its edges. Cover it all over with tinfoil and leave it for the night between boards to dry. Draw a circle 1 in. in diameter in the centre of one side, and remove the tinfoil within it. On the bare circle glue a cork. Round off the top of the cork and fix in it a glass rod 4 in. long. Clean and varnish the rod. Lay a piece of ebonite six inches square on a sheet of tinfoil and turn one edge of the foil over the ebonite so as to cover about half an inch of the upper surface. Rub the ebonite with flannel and put on the cover. The turned up edge removes the negative electricity, so that it should be unnecessary to touch the cover to obtain a charge of positive electricity upon it when it is removed from the ebonite. It will perhaps be better to make sure and to touch the cover with the finger as well.

(*b*) Copy Fig. 92. Using + to represent positive electrification

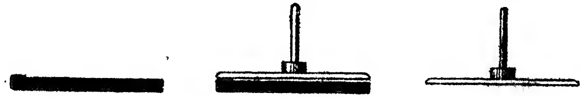


FIG. 92.—To be copied by the student (see Exercise 94 *b*).

and – for negative, fill in the electrical condition of each part of the electrophorus in the stages represented.

95. Construction and Use of a Leyden Jar.

(*a*) Coat a wide-necked glass bottle, both inside and outside, up to the shoulder with tinfoil (Fig. 93), warm it, and varnish it with shellac. When dry, place a piece of wood, in which a wire with a ring or a knob at the top has been fixed, in the bottle, and secure it in position with plaster of Paris. Attach a short length of brass chain to the lower end of the wire, so as to ensure good connection between the wire and inner coating.

FIG. 93.—A Leyden jar.

(*b*) Charge the Leyden jar by means of the electrophorus in the following way. Generate electricity on the cover of the electrophorus, as described in Exercise 94 (*a*). Bring the cover of the electrophorus in contact with the knob of the Leyden jar which stands on the table. Repeat this several times. The Leyden jar is now charged.

Discharge the jar, which may be held in the left hand, by touching the knob with a finger of the right hand. You will receive a slight shock.

Remember that it is dangerous to discharge a *strongly* charged jar in this manner. In such cases a pair of discharging tongs, like those shown in Fig. 94, should be used.

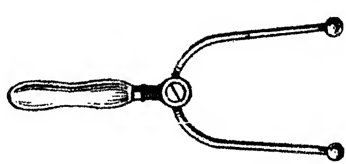


FIG. 94.—Discharging Tongs.

(*c*) Support a dry board on four strong glass tumblers, which have been varnished. Stand on the board and so insulate yourself. Hold the Leyden jar in your left hand as before, and charge it from your electrophorus.[1] Still holding the jar in your left hand, bring a finger

[1] If found necessary an electrical machine should be used for this experiment.

of your right hand over the disc of an electroscope. Notice the divergence. You are evidently electrified.

(*d*) Stand the Leyden jar on an insulated support. Connect its outer coating to the disc of an electroscope by means of a copper wire. Bring the charged cover from your electrophorus in contact with the knob of your Leyden jar. Notice the divergence of the leaves of your electroscope. Remove the wire by the help of a rod of sealing-wax, and find out the kind of electrification producing the divergence.

(*e*) Charge the Leyden jar by holding it by its knob in the left hand, and bringing the cover of the electrophorus in contact with the outer coating several times. Place it on an insulating stand, and connect its inner and outer coatings with discharging tongs.

(*f*) Place the Leyden jar on the insulating stand again, and this time connect the knob with the disc of the electroscope, and the outer coating with the cover of the electrophorus. Observe the divergence of the leaves, and test the kind of charge in the leaves. Record the result.

96. Distribution and Density of Electric Charge.

(*a*) Charge, by means of an electrophorous or electrical machine, the different shaped metal conductors which you have insulated, either by supporting on an insulating stand or by hanging from your retort stand by dry silk ribbons. Proceed to examine the distribution of the charge by means of your proof plane. Bring the proof plane into contact with any part of the conductor, and quickly transfer it to the disc of the electroscope. Notice, by means of an insulated paper scale placed inside the electroscope (Fig. 96), the amount of the divergence of the leaves. Discharge the electroscope. Then touch another part of the metal conductor, repeating the process all the way round the conductor.

(*b*) Map the results obtained in the previous Exercise. Draw the outline of the conductor, and round it trace a dotted line,

arranging the line at a distance from the figure of the conductor proportional to the amount of divergence obtained in the leaves of the electroscope, after it has been touched by the proof plane which has been previously in contact with the corresponding part of the conductor. See Fig. 95.

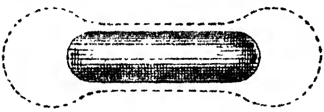


FIG. 95.—Distribution of electric charge on a cylindrical conductor.

This dotted line indicates roughly the amount of the electric charge upon unit area of the surface of the conductor, and this is known as the *Electric Density* of the charged conductor.

(*c*) Bend a thistle-headed tube twice at right angles as shown in Fig. 96. Pass the end of the tube through a hole in an india-

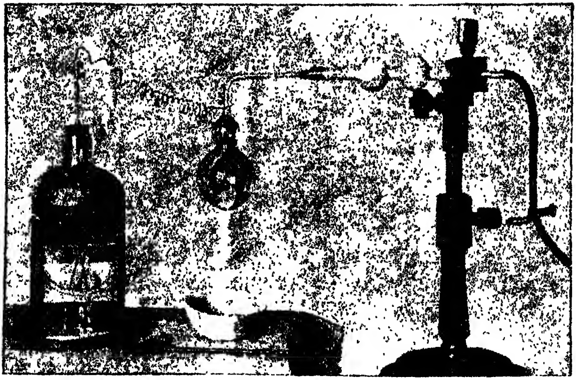


FIG. 96.—Soap-bubble experiment (after Hadley).

rubber stopper, which fits in one end of a tube filled with lumps of calcium chloride Another tube is passed through a stopper in the other end of the calcium chloride tube, and to the free end of the tube is fixed a piece of india-rubber tubing provided with a clip. The calcium chloride tube itself is coated with paraffin wax—painted on when melted. Connect the

thistle head to the disc of your electroscope by means of a copper wire, and bend one end of the copper wire so that its pointed end is well inside the thistle head. Clamp the calcium chloride tube so that the thistle head is about 20 cm. above the table. Raise an evaporating basin containing a solution of Castile soap in methylated spirit up to the thistle head, open the clip and blow a bubble. Charge the electroscope (by means of a proof plane) until there is a fair divergence of the leaves. Now open the clip and blow down the tube and so cause the bubble to increase in size. Similarly open the clip and suck air out of the tube and so decrease the size of the bubble. Observe and record the effects on the leaves.

97. Electric Screening.

(*a*) Make a cylinder of fine wire gauze of such a size that it will completely enclose your electroscope and stand three or four inches above its disc. Cover it with a piece of gauze. Connect the screen to the earth by attaching a wire to it and to a gas pipe. Bring a strongly charged body, such as the ebonite plate of your electrophorus after it has been rubbed with flannel, near the outside of the gauze cylinder. Notice there is no divergence of the leaves.

Make a sketch of the apparatus. Using + and − signs, and bearing in mind what you have learnt of induction, sketch the distribution of the electric charge and try and understand why there is no divergence of the leaves.

(*b*) Surround the charged body with a wire gauze screen connected with the earth and examine its effect on the electroscope.

(*c*) Examine the effects of bringing a disc of metal held in the hand between a charged body and the electroscope.

CHAPTER XIV.

PROPERTIES OF ELECTRIC CURRENTS.

98. Fundamental Experiments.

(*a*) Prepare some dilute sulphuric acid containing one part of strong acid to eight parts of water. First measure out the water into a large beaker, and then gently pour the measured quantity of strong acid into the water, keeping the latter briskly stirred with a glass stirring rod. Having noticed the large amount of heat generated set the mixture on one side to cool.

(*b*) Plunge a strip of ordinary commercial zinc into a beaker of cold dilute sulphuric acid prepared in this way. Notice the brisk evolution of gas which takes place.

(*c*) Repeat the exercise, substituting first a rod of pure zinc and then a strip of copper. Observe that there is no chemical action in either case.

(*d*) Place the rod of pure zinc and the strip of copper into the dilute acid, taking care that the two metals do not touch one another. No gas is given off from either metal.

Now tilt the pieces of metal towards one another until they touch outside the liquid. Observe that bubbles of gas appear on the copper plate.

(*e*) Take the pieces of copper and zinc in the last exercise out of the acid, wash them under the tap, and carefully dry them on clean blotting paper. Weigh both pieces of metal and record their masses thus:

Mass of rod of pure zinc, - - - ...... grams.
Mass of strip of copper, - - - ...... grams.

Now replace them in the dilute acid and make them touch outside the liquid, or connect them by a piece of copper wire, and allow the action which ensues to continue for ten to fifteen minutes. Then remove them from the acid and wash, dry and weigh them as before. Record your result beneath the last entry thus:

After 15 minutes' action.

Mass of zinc rod, - - - -	...... grams.
Mass of copper strip, - - - -	...... grams.

Notice that while the mass of the zinc has diminished that of the copper has remained unaltered.

(*f*) Prepare a plate of amalgamated zinc by dipping a plate of ordinary commercial zinc into dilute sulphuric acid, and, after it has been acted upon for a minute or two, rub some mercury completely over its surface with a piece of cloth. Repeat Exercise 98 (*c*), and observe that amalgamated zinc behaves just like pure zinc.

99. Magnetic Action of Electric Current.

(*a*) Into some dilute sulphuric acid contained in a beaker plunge a plate of amalgamated zinc and one of copper, to each of which a copper wire is attached by a suitable binding screw.

There is no chemical action until the free ends of the wires are joined, when, as before, bubbles of gas are seen to collect on the copper plate.

(*b*) Procure an ordinary compass needle, and bring this up and try and arrange matters so that the wire of Expt. 99 (*a*) in connection with the copper and zinc plates is parallel to the magnet and in the same vertical plane. Notice that this is impossible. The wire exerts a force on the needle.

(*c*) Wind a cotton-covered wire which is connected with the copper and zinc plates round a piece of galvanized iron, as in

Fig. 97. Notice that the piece of iron will attract iron filings.

(*d*) Repeat Expt. 99 (*c*), and notice that after a time the force which the wire exerts over the magnetic needle becomes feebler.

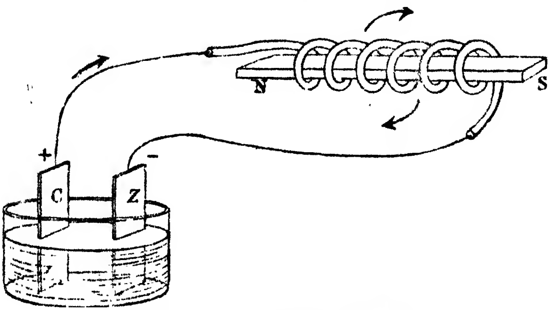


FIG. 97.—To illustrate Exercise 99 (*c*).

Rub the copper plate with a piece of wood until all the bubbles of gas which had collected have disappeared, and notice that the power of the wire to deflect the magnetic needle is regained. (It must be remembered that the bubbles escape freely of their own accord if the copper is rough.)

100. Voltaic Cells.

The simplest arrangement for developing an electric current by means of chemical action has been now described, but there are many others which are much better. They are all called "voltaic" cells after the name of the physicist Volta, who was the first to develop an electric current by chemical means.

To be of any practical value the current from the voltaic cell must not in a short time become much weakened, as in the simple device adopted in Expt. 99 (*d*), as soon as bubbles of gas had collected over the copper plates. Some means have to be taken to prevent this weakening of the

current by the bubbles of gas, or, as it is called, the *polarization* of the cell.

Polarization is prevented in two ways: (1) by mechanical, (2) by chemical means.

Daniell's Cell.—In most of the cells in which polarization is prevented by chemical means there are really two vessels, one placed inside the other. The inner one is made of some porous kind of earthenware which permits a slow passage through it of the liquids on either side of it. In Daniell's cell the outer vessel is of copper and serves as the copper plate. This outer vessel contains a solution of copper sulphate (blue vitriol), the strength of which is maintained by placing some crystals of the same substance on a tray, which extends round the top of the inside of the copper vessel (Fig. 98). The inner porous pot contains dilute sulphuric acid into which dips a rod of amalgamated zinc.

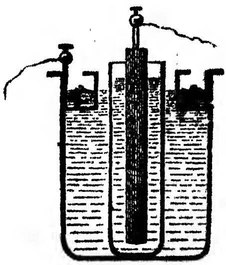


FIG. 98.—A Daniell cell.

(*a*) Examine the parts of a Daniell cell. Connect covered copper wires to the binding screws—one connected with the outer copper vessel, the other with the rod of zinc. To charge the cell proceed as follows: Fill the inner vessel with dilute sulphuric acid, and then three parts fill the outer vessel with copper sulphate solution.

Bunsen's and Grove's Cells. The only difference between these two kinds of voltaic cells is that, whereas, in the former a piece of hard carbon replaces the copper plate, in the latter there is a plate of platinum. Owing to the cheapness of the carbon, Bunsen's cell is the most commonly used.

In Bunsen's cell there are two earthenware vessels, the inner smaller one alone is porous and is filled with strong nitric acid, into which the pieee of carbon dips. The

outer vessel contains dilute sulphuric acid, and in it is placed the zinc plate, which is usually made cylindrical in shape. The arrangement of the parts is easily understood by a reference to Fig. 99.

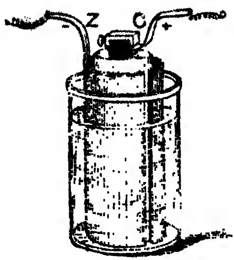


FIG. 99.—A Bunsen cell.

(*b*) Examine a Bunsen cell. Fit up and charge it, and, in the same way as before, satisfy yourself that an electric current is circulating. Also notice that a small spark occurs when the ends of the two wires from the carbon and zinc poles are suddenly brought together or separated. The current flows from the carbon to the zinc outside the cell.

(*c*) A convenient cell for use in the laboratory may be made as follows:[1]

To one end of a piece of hoop iron, 4 inches by 1 inch, solder one end of a piece of cotton-covered copper wire. Scrape the cotton covering off another piece of copper wire, and bind the bare wire firmly in six or eight turns round the end of a piece of electric light carbon 4 inches long. Fix the carbon and iron together with string, keeping them from actual contact by small pieces of wood or cork. Insert the carbon and iron into a strong solution of ferric chloride in a small wide-mouthed glass bottle.

When the cell is not required for sending a current the iron and carbon should be removed from the ferric chloride solution.

101. Direction in which a Magnetic Needle is deflected by the Electric Current.

(*a*) Using whichever kind of cell is most convenient, proceed to study the action of an electric current upon a compass needle placed in the magnetic meridian. Stretch a piece of covered

[1] From the syllabus of the course of Practical Physics at the Royal College of Science, South Kensington.

copper wire, about a yard long, between two universal joints, and arrange it in the magnetic meridian. Call one end *A*, the other *B*. To each end of this wire attach binding screws of the pattern shown in Fig. 100. Put an ordinary compass needle *under* the wire and let the needle come to rest; it will of course, in the circumstances, be parallel to the wire. Connect the wires from a single voltaic cell with the binding screws. Notice and record the direction in which the marked end of the magnetic needle is deflected. Disconnect the wires from the battery, and rearrange them so that the wire from the zinc plate of the battery is now in connection with the end of the supported wire to which the other plate was before connected. Observe that the marked end of the needle is now deflected in the opposite direction.

FIG. 100.—A binding screw.

(*b*) Repeat the exercise, this time arranging the magnetic needle *above* the support. Notice and record the way in which the needle is deflected. Connect the wires in the second way described in the last experiment, and again observe and record the direction in which the needle is deflected.

Make a table of the results, and observe that in each case the rule known as that of *Ampère* holds true, viz.:

> That if you imagine yourself to be swimming in and with the electric current, and facing the magnetic needle, then the marked end of the needle is always deflected to your left hand.

DIRECTION IN WHICH CURRENT FLOWS ALONG WIRE *AB*.	POSITION OF NEEDLE.	DIRECTION OF DEFLECTION OF MARKED END OF NEEDLE VIEWED FROM ABOVE.
Example— *From A to B*	*below*	*to left.*

(*c*) Place the compass needles in the magnetic meridian as

before, and connect the terminals of your cell with the copper wire. Observe and record the direction in which the north end of the needle moves for the four following cases with the wire vertical: (i.) near north end and current running down, (ii.) near north end and current running up, (iii.) near south end and current running down, (iv.) near south end and current running up. Remember that the current flows from the carbon or copper outside the cell.

(*d*) Support the compass needle on a piece of cardboard, held horizontally in a clamp; now bend the wire through which the current was passed in the previous exercises, so that the needle can be arranged in the loop of wire formed (Fig. 101). Arrange the loop of wire and the needle in the magnetic meridian, pass the electric current, and notice the amount of deflection of the needle.

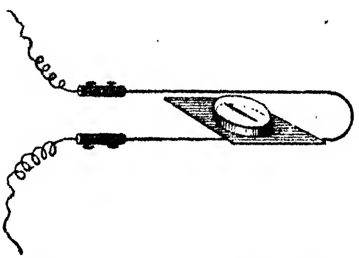


FIG. 101.—Principle of the galvanoscope.

(*e*) Now coil the wire so that there are two lengths above and below the needle, and repeat the previous experiment. The deflection of the needle is greater than before. This experiment illustrates the principle of construction of the *Galvanoscope.*

102. Magnetic Field due to a Current.

(*a*) Place the wire vertical which in the previous experiments was arranged in the magnetic meridian. Hold a compass needle at the side of the wire and then proceed to move it slowly round the wire. Change the connections of the wire with the battery and try again. Record your observations.

The needle always tends to set itself at right angles to the line joining its centre to the nearest part of the wire.

If a very strong current—say that from six quart Bunsen cells—is available, perform the following experiment:

(*b*) Before connecting the vertical wire in the last experiment with the poles of the battery, thread on it a fairly large piece of cardboard through which a hole has been punched. Connect up the battery. Fix the card horizontally by means of a wooden universal joint, and sprinkle iron filings upon it. Gently tap the card and observe and sketch the arrangement of the filings in the neighbourhood of the wire.

Each filing behaves in a precisely similar manner to the magnetic needle in Exercise 102 (*a*).

103. Solenoids.

(*a*) Make a spiral or helix in the following manner: Hold, with the thumb of the left hand, the end of a piece of covered copper wire securely in front of a piece of glass tubing (or an old card-board tube will do) three-quarters of an inch in diameter. With the right hand wind the wire round the tube, bending it to the right and winding upwards. Bring the ends of the wire towards the centre of the spiral and bend them down so that the terminal pieces are vertical. Now take two pill boxes, one larger than the other, and glue the smaller in the middle of the other, so that the larger box contains two concentric compartments Pour a little mercury into each compartment and dip the ends of the wires from a Bunsen's cell (two if necessary) into the mercury, one wire in the outside compartment and the other in the inner. Hang the spiral by means of threads (Fig. 102) in such a way that its vertical terminals dip into the mercury, one terminal in each compartment.

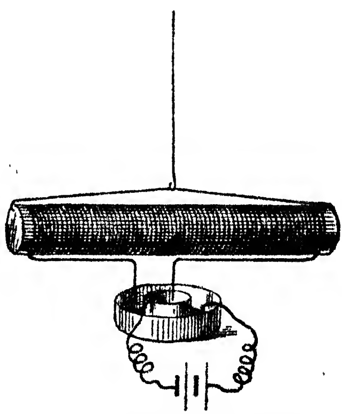


FIG. 102.—Experiments with solenoid.

(*b*) Examine how the spiral, round which a current is now circulating, behaves towards a magnet. Bring a bar magnet near the coil. Observe that the coil turns to face the pole of the magnet and approaches it. Reverse the magnet. The coil is repelled, turns round, and then approaches again. Notice the direction in which the current circulates and record the results you observe with both poles of the magnet.

Notice and record that the coil sets with its plane perpendicular to the meridian when only acted upon by the earth's magnetism.

(*c*) By the aid of a magnetic needle show that the helix behaves just like a bar magnet, one end acting as a marked pole, the other as an unmarked pole.

The polarity of the coil is so related to the direction of the current that on looking at the end which behaves as a south pole, the current circulates in the same way as the hands of a watch.

(*d*) Remembering that the current outside the liquid begins at the carbon pole of a Bunsen cell, follow its direction round the helix and satisfy yourself of the truth of the above statement. Make a sketch in your note book, mark the direction of the current with arrows, and place the letter *S* for the unmarked end of the helix and *N* at the other end (Fig. 103). This drawing will record your result.

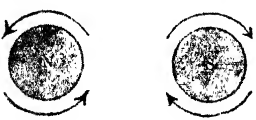


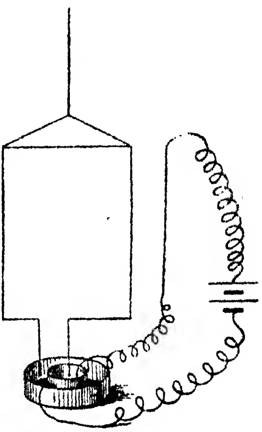
FIG. 103.—The result of Exercise 103 (*d*).

(*e*) Cover about four inches of a narrow glass tube of convenient length with covered copper wire wrapped round it as in making a spiral. Support the glass tube horizontally, and place a sewing needle just in one end of the tube. Now send a current from two or three Bunsen cells connected in series.[1] Observe that the needle slides into the tube—and perhaps out at the other end.

[[1] That is to say, with the carbon of one cell connected to the zinc of the next; one end of the wire round the glass tube is connected with the free carbon plate, and the other end to the free zinc plate.]

104. Attraction and Repulsion of Currents.

(*a*) Bend a piece of covered copper wire into a rectangle as shown in Fig. 104 with the ends bent down vertically. Hang it by means of thread so that the vertical ends dip into the two compartments of the pill box containing mercury. Take a second wire the middle part of which is straight. Connect one end with the carbon pole of two or three Bunsen cells arranged in series and the other end with the mercury in the outer compartment. The zinc pole of the battery is connected with the mercury in the inner compartment. Hold the middle straight part in the hand and bring it towards one long side of the rectangle in such a manner that the wires which approach one another are parallel. Notice and record the result.



F G. 104.—Attraction and repulsion of currents.

Reverse the straight part of the wire so that the end originally beneath is now uppermost, and again notice and record the result.

You will learn that

(i.) Two parallel currents flowing in the same direction attract one another.

(ii.) Two parallel currents flowing in opposite directions repel one another.

(*b*) Make an open helix of elastic copper wire. Hang it vertically. Let the lower end just dip into a small cup of mercury which is in connection with one pole of a battery. Connect the other end of the wire with the other pole. Observe the vibration of the wire. From the results obtained in Ex. 104 (*a*) try to account for this vibration.[1]

[[1] Very springy wire must be used, and the experiment is assisted by inserting a cylindrical bar magnet or a core of soft iron into the helix.]

105. Motion of a Conductor conveying a current in the Magnetic Field.

(*a*) Place a shallow flat-bottomed dish containing mercury on the pole of a bar magnet. Connect wires to the terminals of a Bunsen cell and dip the ends into the mercury. Notice the stream of mercury which sets in between the wires. Make the motion of the mercury more evident by dusting a little powdered chalk on the surface of the mercury. Change the connections with the battery, also the pole of the magnet, and deduce the general relation between the direction of motion, the direction of the current, and the lines of magnetic force, Ex. 102 (*b*).

CHAPTER XV.

ELECTRICAL MEASUREMENTS.

For accurate electrical measurements, a sensitive *galvanometer* is required, but instructive results may be obtained by means of a simple instrument which can be constructed as follows:

106. Construction of a Galvanometer.

(*a*) Obtain an empty cardboard box of the size in which quarter plates are sold for photography. Glue the inside of the rim of the cover, and then fit the cover upon the box. When the glue has dried, the cover will be firmly fixed upon the box, if it is a well-fitting one. Wind around this box lengthways about four yards of silk-covered copper wire, size No. 20 or No. 22, taking care that the coils do not overlap one another. Bring the two ends of the wire to one end of the box, and cut them off about two inches from the coils. Paint the coils with shellac

varnish, so as to stiffen them and make them adhere to the box. When the varnish is dry cut round the box at a distance of about $\frac{1}{4}$ of an inch from each side of the coils. You will thus obtain a rectangular frame, upon which several coils of wire are wound, as shown in Fig. 105. Obtain a block of wood about $\frac{1}{2}$-inch thick, having a breadth and width slightly greater than the length of the coil. Fix upon the top face of the block a card-board circle graduated into degrees, so that the zero of the circle is in a line with the middle of one of the top edges. At the centre of the circle fix a needle upright, and point upwards. The point of the needle should be at a height above the circle equal to half the shortest distance across the rectangular frame

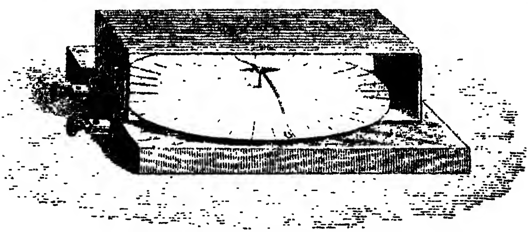


Fig. 105.—A simple galvanometer.

carrying the coils of wire. Make a hole at the centre of one of the long sides of the frame, and then place the coil upon the graduated circle, so that the needle passes through the hole. By means of two narrow strips of brass or zinc fix the frame upon the block, so that its length is at right angles to the zero line of the graduated circle. Scrape the silk off the two ends of the coils, bend the wires over one edge of the block, and wind them round binding-screws fixed into the wood, as shown in the illustration. Obtain a well-magnetized compass needle, not much longer than the width of the coils, and fix at right angles to it, with a small piece of wax, a light pointer made of aluminium wire, or glass tube drawn out to a thin thread. The wire or glass should be slightly curved downwards from the needle, and of such a length that the ends are directly over the degree marks on the graduated circle.

To use this galvanometer, the block is turned until the coil is parallel to the compass needle, and therefore in the magnetic meridian. One end of the pointer should then be directly over the zero mark on the circle. If it is slightly on one side of that position, the block should be turned until the pointer is at the zero mark, or allowance should be made for the difference when making observations with the galvanoscope. To keep the block firm in the adjusted position, it is advisable to fix three short nails in the bottom, so that the points project very slightly, and can be pressed into the table or bench upon which the galvanometer rests. A glass evaporating basin with upright sides may be placed over the instrument to protect it from draughts. The sensitiveness of the galvanometer may be reduced by placing a long magnet in a line with the coil, and with its *N* pole pointing north.

107. Experiments with a Galvanometer.

(*a*) Connect the binding screws of the galvanometer, arranged with its needle and coil in the magnetic meridian, in succession to the poles of (i.) simple cell of Exercise 99 (*a*); (ii.) a Daniell's cell; (iii.) a Bunsen's cell. Notice and record the amount of deflection of the pointer in each case using, if necessary, a magnet to diminish the deflection in the manner already described.

Set the galvanometer east and west and repeat the experiment. Record and try to explain the result

(*b*) Fasten the two ends of the wires from the galvanometer arranged as in Exercise 107 (*a*) to two different metal plates, e.g. zinc and copper. Dip the metals successively into different liquids contained in beakers, such as dilute acids, salt solutions, and alkalies. Notice and record the amount of deflection. Vary the metals and repeat.

(*c*) Noticing the general direction of the deflection of the pointer in each of the experiments, deduce by the aid of Ampère's rule the direction in which the current flows in each case. Record the results.

(*d*) Bring a bar magnet near to the galvanometer, and

observe the effects on the amount of deflection of varying its distance from the instrument when a current is passing.

108. The Mirror Galvanometer.

(*a*) Examine a mirror galvanometer, and compare its parts and accessories with Figs. 106 to 108. *B* is a wooden base supporting a pillar *P*, bored with a small hole passing along its

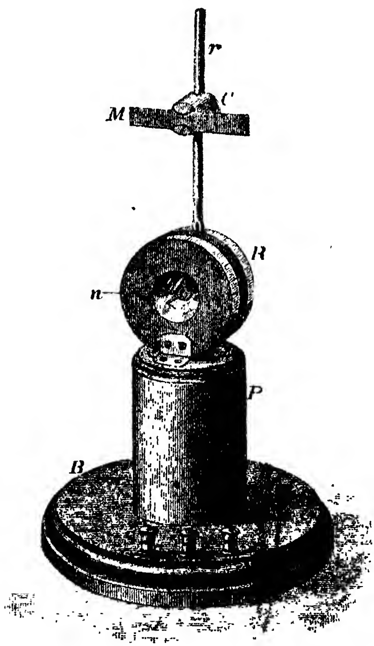


Fig. 106.—A simple mirror galvanometer.

axis. *R* is a reel with flanges and a central hole, having a small recess on one face and a plug to fit it. A round piece of glass for a window fits into the recess already mentioned. A brass

rod *r* supports a *directing magnet M*, which is fitted into a cork *C*, or may slide, by means of a hole through it, up and down the rod The magnetic needle is attached to the back of the mirror *n* It has a damper of aluminium foil, and is suspended by a fibre of raw silk *S*, are binding screws in connection with the ends of the coils of wire. The parts of the scale, lamp, and lens are easily understood from the illustrations

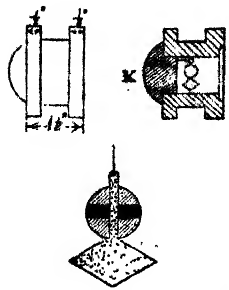


Fig 107 – Parts of a mirror galvanometer

(*b*) See that the mirror swings freely within its hole when the instrument is in the magnetic meridian Set the scale up a metre away, and see that the centre of the scale is opposite to, and parallel with, the mirror Raise the galvanometer or scale until the image of the lamp flame, at the back of the scale, falls

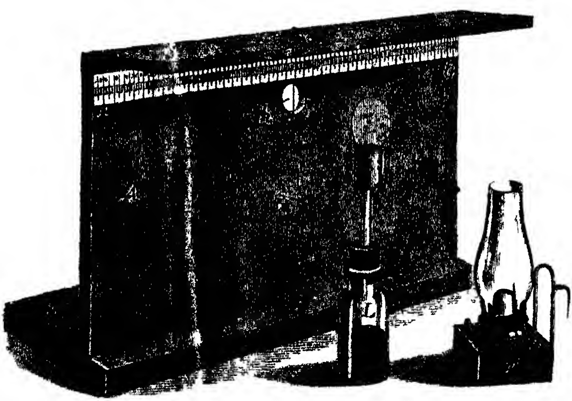


Fig 108 – Scale lam and lens for use with mirror galvanometer

on the scale Focus, by means of the lens, until a distinct image of the wire (Fig 108) is seen on the scale. By moving the

directing magnet, bring the image of the wire to the middle of the scale. The apparatus is now ready for use and can be employed for the following experiments.

109. Electrical Resistance.

(*a*) Connect one pole of a Bunsen's cell with one of the binding screws of your galvanometer. Join the other binding screw of the galvanometer and the other pole of the battery with a yard of fine German-silver wire. Notice the amount of deflection of the pointer. Substitute a yard of thinner German-silver wire for the first piece, and again notice the deflection. It will be much less.

Similarly compare the electrical resistance of pieces of thick and thin copper wire.

(*b*) Solder, or tightly twist at the extreme ends, two pieces of bare German-silver wire of different thicknesses and lengths together, and by means of a suitable binding screw fix the joined ends of the wires to your working table or to a board.[1] Connect the binding screws to a Daniell's cell. Attach long covered wires to the galvanometer, and with the free ends of these wires touch the German-silver wires in different points. When one free end is in contact anywhere with one of the German-silver wires, you can find a point on the other similar wire on touching which with the free end of the other galvanometer wire there is no deflection of the galvanometer pointer.

(*c*) Having arranged things as in the last Exercise, move one of the points of contact. A deflection is obtained.

Again find the position where there is no deflection, and measure the lengths of wire on each side of the points of contact of the galvanometer wires. Prove that the ratio of these parts into which the two German-silver wires are divided are equal.

Since the electrical resistance of a wire increases with its length, the ratios just obtained are also the ratio of the

[1] Caution! The wires should not touch each other except at their extreme ends.

electrical resistances of the parts into which the wires are divided. This is the principle of the *Wheatstone Bridge.*

(*d*) In the arrangement of apparatus used in the last exercise interchange the connections, *i.e.* join the wires from the galvanometer to the binding screws, and the wires from the battery to the German-silver wires. This makes no difference to the result.

The resistance which the liquid of a cell offers to the passage of the current may be observed as follows, but a galvanometer having a single thick coil or a strip of copper is required for the experiment.

(*e*) Pierce the axis of an ordinary cork with the supporting wire of the copper plate of a simple voltaic cell, and mount the zinc plate on a cork in a similar manner. Bore two transverse holes through both corks on opposite sides of the axis, and of sufficient size to admit lengths of glass rod. Support the two corks on two parallel pieces of glass rod resting across the top of a large beaker in such a manner that the distance apart of the plates can be readily varied. Fill the beaker with very dilute sulphuric acid, and connect the plates to a galvanometer having a thick coil by means of copper wires. Place the plates close together and observe the deflection. Separate them gradually and observe how the deflection diminishes, showing that the resistance of the cell is increased when the length of the liquid column between the two plates is increased.

Now remove some of the acid by means of a pipette, so as to reduce the cross-section of the liquid column. Notice how the deflection diminishes as the liquid gets lower and lower.

110. The Passage of the Electric Current through Liquids.

(*a*) Fit up a Bunsen's cell for the generation of an electric current. Attach pieces of platinum foil, by means of suitable binding screws, to the ends of two copper wires. Attach one of these wires to one pole of the battery. Connect the other pole to one of the binding screws of a simple galvanoscope, and to

the other screw of the galvanoscope attach the remaining wire with the platinum plate on the end. Dip the platinum plates—(i) into some mercury, and notice there is a great deflection of the needle of the galvanoscope and no alteration of the mercury; (ii) into some turpentine, and notice there is no deflection of the needle; (iii) into some acidulated water, and notice there is a smaller deflection than in the first case, and at the same time there are bubbles of gas given off from both platinum plates.

Passage of the Current through Mercury. The great deflection of the needle of the galvanoscope reveals the fact that a considerable current passes through its coil of wire: hence mercury is a good conductor of the electric current, or expressing the same truth in other words, it offers very little resistance to the flow of the current.

Passage of the Current through Turpentine. There is in this case no deflection of the needle of the galvanoscope; it is therefore evident that no current passes through the coil of wire round the needle, and since the battery is arranged precisely as in the previous experiment with the mercury, the explanation must be that the turpentine prevents the flow of the electric current round the circuit. Turpentine is consequently known as a *non-conductor*, a class of bodies which also includes such liquids as petroleum and other oils.

Passage of the Current through Acidulated Water. In this case the current is conducted and the liquid decomposed by the passage of the current. This is the condition of things in all liquid compounds which conduct the electric current. Such a decomposition is known as *electrolysis*.

Potential and Electromotive Force.

Difference of Potential or Electro-motive Force. A wire connecting the poles of a Bunsen or other cell is said to have an electric current flowing along it.

The use of such words as "flow" and "current" will probably suggest previous facts which the student has learnt. It has been seen that a flow of heat takes place

from a body of high temperature to one of low temperature when they are placed in contact, and that such flow continues until both bodies are of the same temperature.

Similarly, there is a flow of water from one vessel to another, which are in connection, if the level of the water in one vessel is higher than in the other. Hence we are face to face with the question, What difference is there between the poles of a cell which causes the condition of things called the electric current? The name given to the difference of condition in the plates of the battery which corresponds to temperature and water-level is *potential*. The electric current continues to flow along the copper wire until the potential of the two plates becomes the same; then it ceases.

The electrical condition of the plates becomes altered by placing them in the liquids of the cell, but the final state is different in the two cases. The carbon or other + plate is at a higher potential than the zinc plate, and, consequently, when the plates are joined outside the liquid by a copper wire there is a flow of the electric current *from the carbon to the zinc*. The difference of potential which causes the flow is maintained by the solution of the zinc in the acid. Or, speaking in terms of energy, the work of maintaining the current is performed by the solution of the zinc. This is similar to the maintenance of the work done by a steam-engine by the burning of the coal in the furnace. It was for this reason that you found the zinc decreased in mass in Ex. 98 (*c*), after the electric current had flowed for some time along the joined wires.

It is customary to give the name *electro-motive force* to the difference of potential which exists between the plates of an electric battery. But though the term electro-motive force is used to speak of this difference of potential, it is not a force in the sense that the word was used in the Exercises of Part I. A force is that which causes motion in matter, but an electro-motive force results only in a motion of electricity, which is not matter at all.

Fall of Potential along a Wire traversed by an electric current. Referring again to Expt. 109 (*b*), where the poles of

the battery are connected with the ends of the German-silver wires, as you know, the current starts from the carbon pole of the battery and eventually flows along the German-silver wires back to the zinc plate of the battery. There is a gradual fall of the electric level or potential all along both wires. When the copper wires from the galvanometer are connected with different parts of the German-silver wires the result, noticed in the deflection, or otherwise, of the spot of light, depends entirely upon the potential at the points of contact. A current always flows from a place of high potential to a place of low potential if these are connected by a conductor. When there is no deflection of the needle, or of the spot of light, it means that the places of contact are at the same potential.

111. Relation between Current, Resistance, and Electro-motive Force.

Ohm's Law. The relation between the difference of potential or electro-motive force, the resistance of the conductor, and the current traversing it was first clearly stated by G. S. Ohm in 1827. The relation which this physicist established and which is known after him may be stated thus:—

The current passing along a conductor varies directly as the electro-motive force or difference of potential between its ends and inversely as the resistance of the conductor.

The greater the difference of potential the greater is the current; the less the resistance the more current will there be, or what is the same thing, the greater the resistance the less the current.

It is usual to represent the current by C, the difference of potential by E, and the resistance by R, and to express Ohm's law as a simple equation

$$C = \frac{E}{R}$$

(*a*) Procure two known high resistances, one marked 100

Ohms[1] and the other 200 Ohms, and connect them, one at a time, in series with the mirror galvanometer and a Daniell's cell. The copper wires should not be long, and the deflection[2] in the second case will be found to be about half that of the first.

(*b*) Connect the two resistances in series and so obtain a total resistance of 300 Ohms—again notice the deflection.

An electric current is thus shown to diminish with an increase of resistance, and increase with a diminution of resistance.

(*c*) Connect in series a known resistance of say 1000 Ohms, a Daniell's cell, and your mirror galvanometer. Notice and record the amount of deflection. It may be necessary to raise the directing magnet. Now substitute two cells connected in series, that is, as in Expt. 103 (*e*). The deflection is *about* twice as great.

The current is thus shown to increase with a greater electromotive force.

112. Wheatstone's Bridge.

(*a*) Examine a Wheatstone's bridge and compare its parts with Fig. 109.

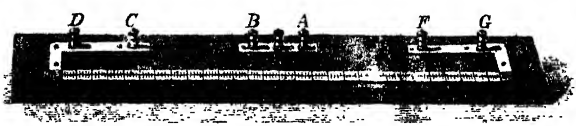


Fig. 109.—Wheatstone's Bridge.

The Theory of Wheatstone's Bridge is very easily understood after the performance of Expt. 109 (*b*). The current from

[1] An Ohm is the standard of resistance and is equal to the resistance of a uniform column of mercury 106·3 cm. long and 14·4521 grms. in mass at 0° C.

[2] If a mirror galvanometer is used, and is so sensitive that with 100 Ohms the spot of light is off the scale, you must lower the directing magnet till the light is just *on* the scale; then break the circuit, and by means of the directing magnet adjust the spot of light to the centre of the scale and start the experiment again.

the battery arriving at A divides; part traverses the path ACB, and the remainder the alternative path ADB. Along both paths electrical resistance is met, and the electromotive force falls uniformly along ACB and ADB. The rate at which it falls depends entirely upon the resistance of the path. Now when C and D are joined by the wires

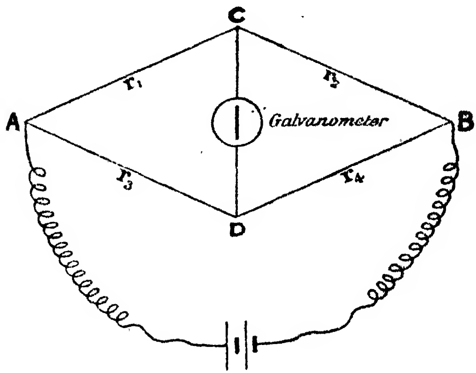


Fig. 110.—Theory of Wheatstone's Bridge.

of the galvanometer, and there is no deflection of the needle, the potentials at C and D are the same, or the resistances of ACB and ADB have been divided proportionately; therefore

$$\frac{r_1}{r_2}=\frac{r_3}{r_4}.$$

When there is a deflection of the needle it means that the potentials of C and D are not the same, and the point of contact of the galvanometer wire at C or at D must be moved in order to obtain no deflection of the galvanometer needle.

(*b*) When you have made out its parts proceed to compare by means of the Wheatstone's bridge the resistances of two wires.

Fig. 111 will show you how to make the necessary connections between the bridge, galvanometer, battery, and resistances to be compared.

The binding screws of the galvanometer are connected by means of covered wires with the ends of the German-silver wire

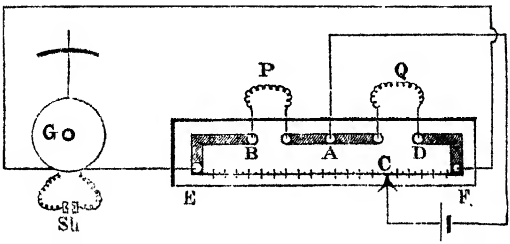


Fig. 111.—How the connections for Wheatstone's Bridge experiments are made.

of the Wheatstone's Bridge at *EF*, or rather by the two binding screws nearest these points. One pole of the battery is joined with the binding screw between *A* and *B* in Fig. 109, and marked *A* in Fig. 111: the wire from the other pole of the battery is free to be moved along the German-silver wire. The two resistances to be compared are joined up between the binding screws *B* and *C*, and *A* and *F* in Fig. 109, as at *P* and *Q* in Fig. 111.

With the free wire touch the fixed wire in the manner shown in the table.

(i.) Touch at	scale reading	10—	deflection	left (say).
,,	,,	90—	,,	right.
(ii.) ,,	,,	20—	,,	left.
,,	,,	80—	,,	right.

Continue to gradually 'pinch-in' towards the correct point. You will finally get, say

Scale reading	40—	deflection	left.
,,	50—	,,	right.

The correct point must be somewhere between these. Proceed more carefully in a similar manner, say 1 cm. at a time, 41, 49; 42, 48; 43, 47 and so on until there is no deflection in either direction on touching the fixed wire with the free one.

Call the final position of wire a distance a from P's end of the bridge. Then,

$$\frac{\text{Resistance of } P}{\text{Resistance of } Q} = \frac{a}{100 - a},$$

when there are 100 divisions on the scale of the bridge.

(*b*) Insert two different lengths, A, B, of wire of the same material and cross-section in the two gaps. Find the place on the wire of the bridge at which contact causes no deflection of the galvanometer. Prove that the lengths of the parts into which the bridge-wire is divided are in the same proportion as the lengths of A and B, measured from where they leave the binding screws, and therefore of the resistances of A and B.

Reverse the positions of A and B, and similarly again obtain a balance. The ratio should be the same as before. If it varies slightly, as it probably will, take the mean of the results.

(*c*) Take two wires, A and B, of the same lengths but of different thickness, or, as it is better to say, of different sectional areas, and insert them in the gaps of the bridge, as in the last experiment. Find the ratio of their resistances in precisely the same way as before.

Now measure their diameters as in Part I., and calculate their sectional areas from the formula

$$\text{sectional area} = \frac{\pi}{4} d^2, \text{ or } \pi r^2,$$

where r is the radius or $d/2$.

Record your results.

Parts into which Bridge-Wire is divided.	Ratio of Resistances	Sectional Area.	Inverse Ratio of Sectional Area
A			
B			
C	1.		

Your measures will show that the following relation holds good:

$$\frac{\text{resistance of } A}{\text{resistance of } B} = \frac{\text{sectional area of } B}{\text{sectional area of } A}.$$

113. Specific Resistances of Wires.

Not only does the resistance of a wire depend directly upon its length and inversely upon its sectional area, but also directly upon what is known as the *specific resistance* of the material of the wire. By the specific resistance of any substance is meant the actual resistance of a cube of such material having a side of unit length. These three factors influencing the resistance of a wire can be combined in a simple equation, thus:

$$\text{The resistance of a wire} = \frac{\text{its length} \times \text{specific resistance}}{\text{sectional area}}.$$

(*a*) Compare the specific resistance (κ) of copper and German-silver.

(i.) Compare their resistances by putting the copper in one gap of the bridge, and the German-silver in the other.

(ii.) Measure their lengths and, after measuring the diameters, calculate the sectional areas. Remember that

$$\text{Resistance of a wire} = \frac{\text{its length} \times \text{specific resistance}}{\text{sectional area}}$$

$$\text{or } R = \frac{l\kappa}{a}.$$

This is true of both wires. Call copper wire (1) and German-silver wire (2), then

$$R_1 = \frac{l_1\kappa_1}{a_1}; \quad R_2 = \frac{l_2\kappa_2}{a_2};$$

$$\frac{R_1}{R_2} = \frac{\dfrac{l_1\kappa_1}{a_1}}{\dfrac{l_2\kappa_2}{a_2}} = \frac{l_1\kappa_1 \times a_2}{l_2\kappa_2 \times a_1}$$

or

$$\frac{\kappa_1}{\kappa_2} = \frac{R_1 l_2 a_1}{R_2 l_1 a_2};$$

and $\frac{R_1}{R_2}$, $\frac{l_2}{l_1}$, and $\frac{a_1}{a_2}$ are all known from the experiment, and so the ratio of the specific resistances is also known.

(*b*) Similarly compare specific resistances of (i.) iron and copper, (ii.) brass and German-silver.

ADDITIONAL EXERCISES.

(L.U., London University; L.C.C., London County Council Intermediate Scholarship Examination; J.O., Junior Oxford Local; J.C., Junior Cambridge Local.)

Heat.

1. Mix equal quantities of ice and salt, and ascertain the lowest temperature reached. Use the mixture to freeze water. (L.C.C. 1898.)

2. Determine the boiling point of the given liquid. (L.C.C. 1898.)

3. Determine the boiling point of water and deduce the pressure of the atmosphere, being given—

Boiling point of water		= 99°	when barometer reads		733 mm.
,,	,,	= 100°	,,	,,	760 ,,
,,	,,	= 101°	,,	,,	787 ,,

(L.C.C. 1897.)

4. Determine the melting point of the given substance. (L.C.C. 1897.)

5. Pour some hot water into the given vessel, and note the temperature every minute as it cools, keeping the water well stirred. Draw the curve of cooling on a sheet of squared paper, and compare the rates of cooling at the temperatures 65°, 55°, 45°. (L.C.C. 1897.)

6.* Arrange an experiment to prove that a blackened metallic surface is a better radiator than a bright metallic surface. (L.C.C. 1898.)

7. Determine the relative thermal conductivities of the three wires supplied.

8. Find the change of volume which a piece of paraffin wax experiences in melting.

9. Fill the given vessel nearly full with boiling water, and take the temperature every minute as it cools. Compare the rates of cooling at 80°, 60°, 40°. After the experiment weigh the vessel and water, and the vessel alone. Being given the specific heat of the material of the vessel, calculate approximately the loss of heat per minute at each of the above temperatures.
(L.C.C 1899.)

10. Find the specific heat of a given metal.

11. Given the specific heat of a certain piece of metal, find that of paraffin oil. (Int. Sci. Hons. L.U. 1896.)

12. Find the latent heat of water. (Int. Sci. Hons. L.U. 1896.)

13. Determine the melting point of paraffin wax.
(Int. Sci. Hons. L.U. 1896.)

14. Determine the expansion of water between two temperatures, by weighing in it a solid of given expansion.
(Int. Sci. Hons. L.U. 1895.)

15. Determine the latent heat of vaporisation of water.

16. Find the expansion of water between the temperature of the room and 80° C. (B.Sc. Pass. L.U. 1895.)

17. Determine the specific heat of a given body by the method of mixture.

18. Determine coefficient of expansion of paraffin oil.

19. Weigh out some water into a flask, heat the flask on wire gauze over a Bunsen burner, and by noticing the rise of temperature in a given time calculate the amount of heat absorbed per minute; then boil the water, and deduce a value for the latent heat of steam. (J.C. Local, 1898.)

20. Raise some water to the temperature 25° C. and dissolve in it such a quantity of salt that a litre of the solution would contain 250 grams of the salt. Then determine the temperature at which the solution begins to boil. (J.O. Local, 1898.)

21. Being given that the specific heat of copper = ·095, determine the specific heat of the given liquid. (L.C.C. 1898.)

22. You are given a calorimeter containing a certain quantity of water; pass dry steam into the water until the temperature rises about 20°. Observe the initial and final temperatures of

the water, and determine the mass of the steam condensed. Deduce the water equivalent of the calorimeter and its contents, being given that the latent heat of steam = 536 units.

(L.C.C. 1898.)

23. Determine the quantity of water contained in the given bottle when the temperature is 20°, and also when the temperature is 60°. Deduce the mean coefficient of apparent expansion of water between 20° and 60°. (L.C.C. 1897.)

24. Determine the latent heat of fusion of ice. (L.C.C. 1899.)

25. Determine the expansion of air at constant pressure between two temperatures, by observing the movement of a mercury index along a uniform fine bore tube open at one end.

(Int. Sci. Hons. L.U. 1896.)

26. Determine the coefficient of expansion of air.

(L.C.C. 1899.)

27. Given the specific heat of copper = ·095, determine the water equivalent of the given calorimeter and its contents.

(L.C.C. 1899.)

Light.

1. Determine the position of the centre of curvature of the given concave mirror by arranging the object in such a position that the image formed is real, inverted, and of the same size.

(L.C.C. 1898.)

2. Determine the position of the virtual image of a candle seen by reflection from a plane mirror by using the given converging lens to give a real image of the virtual image.

(L.C.C. 1898.)

3. Arrange an experiment to show that a ray of light which is incident upon one face of a glass cube and after refraction falls upon an adjacent face, is totally reflected at that face. You are provided with a glass cube, pins and paper. (L.C.C. 1898.)

4. Determine the index of refraction of the glass of the given prism by some simple method. (L.C.C. 1898.)

5. Determine the focal lengths of the two given lenses, the one converging and the other diverging (of greater power). Afterwards arrange the lenses to illustrate the Galilean telescope.

(L.C.C. 1898.)

6. Use the given concave mirror to obtain an image of a distant object, and place the given small plane mirror in such a position that the reflected rays fall upon it, and the image can be viewed without placing the head in front of the concave mirror. (L.C.C. 1897.)

7. You are provided with a large glass cube and some pins, paper, etc. Determine by some simple method the index of refraction of the glass. (L.C.C. 1897.)

8. Prove by experiment that when light is refracted by passing through a prism the angles of incidence and emergence are equal when the prism is placed in the position of minimum deviation. You are provided with pins, paper, etc. (L.C.C. 1897.)

9. Determine the radius of curvature of each face of the given concave lens. (L.C.C. 1897.)

10. Determine the focal lengths of the two given converging lenses. Afterwards place them in contact, and determine the focal length of the combination. (L.C.C. 1897.)

11. Determine the refractive index of the glass of a given lens by measuring the curvatures of the faces with a spherometer and comparing these with the focal length.

(Int. Sci. Hons. L.U. 1897.)

12. Find the refractive index of a block of glass by the use of pins, a drawing-board and a rule. (Int. Sci. Hons. L.U.)

13. Find the refractive index of a prism of glass by the use of pins, a drawing-board and a rule. (Int. Sci. Hons. L.U.)

14. Plot a curve, showing the relation between the distances between two convex lenses, and the distance from one of the lenses of the image formed by the lenses, of a distant object.

(Int. Sci. Hons. L.U.)

15. Find the curvature of the faces of the given concave lens.

16. Plot as a curve the relation between the respective distances, as found by observation, of an object and its image from a given convex lens. (B.Sc. Pass, L.U.)

17. Given two needles on stands and a concave mirror. Arrange the needles so that the point of the one needle is coincident with the real image of the other. Deduce the focal length of the mirror from the measurement of the relative position of the mirror and needles. (L.C.C. 1899.)

18. Given a cube of glass with a straight edge attached to one face, pins and paper. Viewing the straight edge through the opposite face of the cube, trace the course of the refracted rays for different directions of vision. Deduce the index of refraction. (L.C.C. 1899.)

19. Given prism, pins and paper. Prove that in all cases where a ray of light traverses a prism entering at one face, passing through the prism and emerging at an adjacent face, the deviation is towards the thick part of the prism. (L.C.C. 1897.)

20. Given a converging and a diverging lens and an optical bench, show that a diverging lens can render a convergent beam of light less convergent, parallel or divergent. (L.C.C. 1899.)

21. Find the focal length of the given diverging lens. (L.C.C. 1899.)

Sound.

1. Compare the velocity of sound through air and coal gas. (Int. Sci. Hons. L.U. 1895.)

2. Find, by using a tuning fork of known pitch, the density of the wire stretched on the monochord.

3. Find the velocity of sound in a tube by resonances, using the first and second resounding lengths. Correct your results to air at 0°. (B.Sc. Pass, L.U. 1895.)

4. Determine the ratio of the radii of two steel wires from the frequencies of their vibrations under known loads, given a tuning fork. (B.Sc. Pass, L.U. 1895.)

5. Given a sonometer and a rod clamped at one end, find the relation between the length and frequency of the transverse vibrations of the rod. (B.Sc. Pass, L.U. 1895.)

6. Determine the velocity of sound in a given rod by Kundt's method.

Magnetism.

1. Given a pair of bar magnets, magnetize the two given similar pieces of steel by different methods and compare the pole strengths. (L.C.C.)

2. You are given two long thin magnets of the same length, compare their pole strengths (1) by the method of deflection, (2) by the method of vibration. (L.C.C. 1897.)

3. Determine the magnetic meridian, as accurately as you can, with the declination compass.

4. Map the magnetic field in the neighbourhood of a bar magnet placed with its axis in the magnetic meridian, the south-seeking pole being towards the north. From your result mark as nearly as possible the position where a compass needle would have no tendency to set in any particular direction. (L.C.C. 1897.)

5. Make a determination of the magnetic dip at a given place in the laboratory. (B.Sc. Pass, L.U.)

6. Determine the magnetic axis of the given magnetized iron disc.

7. Find the moment of the given magnet.

8. Place the given bar magnet so that its length makes an angle of 45° with the magnetic meridian. Map the magnetic field in the neighbourhood of the magnet by means of a compass needle. (L.C.C. 1899.)

9. Determine the magnetic dip or inclination.

10. Given two pieces of steel of the same dimensions, magnetize one by means of the given bar magnet, and the other by means of the electric current. Compare their pole strengths. (L.C.C. 1899.)

11. Ascertain if the given bar magnet is magnetized so that the magnetic axis is parallel to the line joining the centres of the end faces.

Electricity.

1. Compare the resistances of the two given coils of wire. (L.C.C. 1898.)

2. To the ends of the given battery join a divided circuit, consisting of (1) the two coils A and B joined in series; (2) the stretched wire one metre long. Determine by experiment the point of the wire which is at the same potential as the junction of A and B. (L.C.C. 1898.)

3. Perform Faraday's ice pail experiment. State clearly what you deduce from the experiment. (L.C.C. 1898.)

4. Find the specific resistance of the given substance.

5. Determine the difference between the resistances of the two given coils.

6. Given two coils *A* and *B*. Measure their resistances (1) separately, (2) arranged in series, (3) arranged in parallel. (L.C.C. 1899.)

7. Given two wires of different materials. Determine the ratio of the resistances of two wires of these materials, if the lengths and section are alike. (L.C.C. 1899.)

8. Map with iron filings the magnetic field in the neighbourhood of a coil of wire whose plane is vertical when a current passes through the coil. Make use of the given bar magnet to determine the direction of the current through the coil. (L.C.C. 1899.)

9. Given a Daniell cell (E.M.F. = 1.1 volts). Determine the E.M.F. between the two given terminals connected to a hidden battery. (L.C.C. 1899.)

10. In electrification by rubbing demonstrate the equal production of positive and negative electrification. (L.C.C. 1897.)

TABLES OF PHYSICAL UNITS AND VALUES.*

Equivalents of Metric Weights and Measures in terms of Imperial Units.

METRIC TO IMPERIAL.

Linear Measure:

1 millimetre (mm.) ($\frac{1}{1000}$ m.)	=	0·03937 inch.
1 centimetre ($\frac{1}{100}$ m.)	=	0·3937 ,,
1 decimetre ($\frac{1}{10}$ m.)	=	3·937 inches.
1 metre (m)	=	**39·37 inches.** **3·28 feet.** **1·09 yards.**
1 dekametre (10 m.)	=	10·936 yards.
1 hectometre (100 m.)	=	109·36 ,,
1 kilometre (1000 m.)	=	0·62 mile.

Square Measure:

1 square centimetre	=	0·155 square inch.
1 square decimetre (100 square centimetres)	=	15·50 square inches.
1 square metre (100 square decimetres)	=	10·76 square feet. 1·19 square yards.

Cubic Measure:

1 cubic centimetre	=	0·06 cubic inch.
1 cubic decimetre (c.d.) (1000 cubic centimetres)	=	61·02 cubic inches.
1 cubic metre (1000 cubic decimetres)	=	35·31 cubic feet. 1·31 cubic yards.

*Chiefly compiled from "Smithsonian Physical Tables," prepared by Prof. Thomas Gray, and published by the Smithsonian Institution, Washington, 1896.

Measure of Capacity:

1 centilitre ($\frac{1}{100}$ litre) - - - - -	=	0·070 gill.
1 decilitre ($\frac{1}{10}$ litre) - - - - -	=	0·176 pint.
1 litre - - - - - - -	=	**1·76 pints.**

Mass:

		Avoirdupois.
milligram ($\frac{1}{1000}$ grm.) - - - -	=	0·015 grain.
centigram ($\frac{1}{100}$ grm.) - - - - -	=	0·154 ,,
decigram ($\frac{1}{10}$ grm.) - - - - -	=	1·543 grains.
gramme (1 grm.) - - - - - -	=	15·432 ,,
dekagram (10 grm.) - - - -	=	5·644 drams.
hectogram (100 grm.) - - - - -	=	3·527 oz.
1 kilogram (1000 grms.) - - - - -	=	**2·20 lb. or 15432·356 grains.**
		Troy.
1 gram (1 grm.) - - - - - -	=	0·032 oz. troy. 15·43 grains.
		Apothecaries.
1 gram (1 grm.) - - - - - -	=	0·257 drachm. 0·771 scruple. 15·43 grains.

Equivalents of Imperial Weights and Measures in terms of Metric Units.

IMPERIAL TO METRIC.

Linear Measure:

1 inch - - - - - - -	=	25·4 millimetres.
1 foot (12 inches) - - - - -	=	0·30 metre.
1 yard (3 feet) - - - - - -	=	**0·914 metre.**

Square Measure:

1 square inch - - - - - -	=	6·45 sq. centimetres.
1 square foot (144 square inches) - -	=	9·29 sq. decimetres.
1 square yard (9 square feet) - -	=	0·836 square metre.

Cubic Measure:

1 cubic inch - - - - - -	=	16·387 cub. centimetres.
1 cubic foot (1728 cubic inches) - -	=	0·028 cub. metre.
1 cubic yard (27 cubic feet) - - -	=	0·764 cub. metre.

Measures of Capacity:

1 gill - - - - - - - -	=	1·42 decilitres.
1 pint (4 gills) - - - - - -	=	0·568 litre.
1 quart (2 pints) - - - - - -	=	1·136 litres.
1 gallon (4 quarts) - - - - -	=	**4·546 litres.**

Apothecaries Measure:

1 minim	=	0·059 millilitre.
1 fluid scruple	=	1·184 millilitres.
1 fluid drachm (60 minims)	=	3·552 ,,
1 fluid ounce (8 drachms)	=	2·841 centilitres.
1 pint	=	0·568 litre.
1 gallon (8 pints or 160 fluid ounces)	=	**4·546 litres.**

Avoirdupois Weight:

1 grain	=	0·065 gram.
1 dram	=	1·77 grams.
1 ounce (16 drams)	=	28·35 ,,
1 pound (16 ounce or 7000 grains)	=	**0·4536 kilogram.**

Troy Weight:

1 grain	=	0·065 gram.
1 pennyweight (24 grains)	=	1·55 grams.
1 troy ounce (20 pennyweights)	=	31·10 ,,

Apothecaries Weight:

1 grain	=	0·065 gram.
1 scruple (20 grains)	=	1·296 grams.
1 drachm (3 scruples)	=	3·888 ,,
1 ounce (8 drachms)	=	31·10 ,,

Mensuration.

$\pi = 3{\cdot}14159.$ $\quad\frac{1}{\pi} = 0{\cdot}3183.$

$2\pi = 6{\cdot}28318.$

$\pi^2 = 9{\cdot}8696.$ $\quad\sqrt{\pi} = 1{\cdot}7724.$

Lengths.

Circumference of circle of radius r - - - $= 2\pi r$.

,, ,, ,, diameter d - - - $= \pi d$.

,, ellipse with semi-axes a and b $= 2\pi\sqrt{\frac{a^2 + b^2}{2}}$

Areas.

Triangle, base b, perpendicular h - - - $= \frac{bh}{2}$.

Rectangle, sides b, h - - - - - $= bh$.

Parallelogram, base b, perpendicular h - - $= bh$.

Circle, radius r - - - - - - - $= \pi r^2$.

Circle, diameter d	$=\frac{\pi d^2}{4}$.
Ellipse, semi-axes a, b	$=\pi ab$.
Surface of cube, edge a	$=6a^2$.
Surface of sphere, radius r	$=4\pi r^2$.
Curved surface of right cylinder, r radius, height h	$=2\pi rh$.
Total surface of right cylinder ,, ,,	$=2\pi r(r+h)$.
Curved surface of right cone, r radius, h altitude, s slant height,	$=\pi rs$. $=\pi r\sqrt{r^2+h^2}$.
Total surface of right cone	$=\pi r(s+r)$.

Volumes.

Cube, edge a	$=a^3$.
Rectangular parallelopiped, edges a, b, c	$=abc$.
Pyramid, area of base a, altitude h	$=\frac{ah}{3}$.
Cone, with circular base, radius r, altitude h	$=\frac{\pi r^2 h}{3}$.
Cylinder or prism, area of base a, altitude h	$=ah$.
Sphere, radius r	$=\frac{4}{3}\pi r^3$.

Density, or Mass per Unit Volume.

Common Solids.

Substance.	Mass of 1 Cubic Centimetre in Grams.	Mass of 1 Cubic Foot in Lbs.
Anthracite,	1·4–1·8	87–112
Asbestos,	2·0–2·8	125–175
Beeswax,	0·96–0·97	60–61
Bone,	1·7–2·0	106–125
Borax,	1·7–1·8	106–112
Brass,	8·2–8·7	511–542
Bronze,	8·74–8·89	545–555
Brick,	2·0–2·2	125–137
Butter,	0·86–0·87	53–54
Caoutchouc,	0·92–0·99	57–62
Cement (Loose),	1·15–1·7	72–105
,, (Set),	2·7–3·0	168–187
Chalk,	1·9–2·8	118–175
Charcoal (Oak),	0·57	35
,, (Pine),	0·28–0·44	17·5–27·5

Common Solids.

Substance.	Mass of 1 Cubic Centimetre in Grams.	Mass of 1 Cubic Foot in Lbs.
Clay, - - - - -	1·8–2·8	122–162
Coke, - - - - -	1·0–1·7	62–105
Ebonite, - - - -	1·15	72
Emery, - - - -	4·0	250
Felspar, - - - -	2·53–2·58	158–161
Flint, - - - - -	2·63	164
Gas Carbon, - - - -	1·88	119
German Silver, - -	8·30–8·77	518–547
Glass (Common), - - -	2·4–2·8	150–175
„ (Flint), -	2·9–4·5	180–280
Glue, - - -	1·27	80
Granite, - - -	2·5–3·0	156–187
Graphite, - - - -	1·9–2·3	120–140
Gravel, - - - -	1·2–1·8	94–112
Gum Arabic, - - -	1·3–1·4	80–85
Ice, - - - - -	0·88–0·91	53–57
Ivory, - - - - -	1·83–1·92	114–120
Leather (Dry), - - -	0·86	54
Limestone, - - - -	2·46–2·86	154–178
Magnetite, - - - -	4·9–5·2	306–324
Marble, - -	2·5–2·8	157–177
Meerschaum, - - -	·99–1·28	61·8–79·9
Mica, - - - - -	2·6–3·2	165–200
Paper, - - - - -	0·7–1·15	44–72
Paraffin, - - -	0·87–0·91	54–57
Pitch, - - - - -	1·07	67
Porcelain, - - - -	2·3–2·5	143–156
Pumice Stone. - - -	0·37–0·9	23–56
Quartz, - - - - -	2·65	165
Resin, - - - - -	1·07	67
Rock Crystal, - - -	2·6	162
Rock Salt, - - - -	2·28–2·41	142–150
Sal Ammoniac, - - -	1·5–1·6	94–100
Sand (Dry), - - - -	1·40–1·65	87–103
Sandstone, - - - -	2·2–2·5	137–156
Slag (Furnace), - - -	2·5–3·0	156–187
Slate, - - - - -	2·6–2·7	162–168
Starch, - - - - -	1·53	95
Sugar, - - - - -	1·61	100
Talc, - - - - -	2·7	168
Tallow, - - - -	0·91–0·97	570–605
Tile, - - - - -	1·4–2·3	87–143

Metals.

Substance.	Mass of 1 Cubic Centimetre in Grams.	Mass of 1 Cubic Foot in Lbs.
Aluminium,	2·56–2·80	160–175
Copper,	8·80–8·95	549–558
Gold,	19·26–19·34	1202–1207
Iron,	7·03–7·90	439–493
Lead,	11·00–11·36	686–709
Magnesium,	1·69–1·75	105–109
Mercury,	13·596	848
Nickel,	8·30–8·90	517–555
Platinum,	21·20–21·70	1322–1354
Silver,	10·40–10·57	649–659
Tin,	6·97–7·30	435–455
Zinc,	7·04–7·19	439–449

Liquids.

Substance.	Mass of 1 Cubic Centimetre in Grams.	Mass of 1 Cubic Foot in Lbs.
Alcohol (Ethyl),	0·791	494
,, (Methyl),	0·810	50·5
,, (Proof Spirit),	0·916	57·2
Benzine,	0·899	56·1
Carbolic Acid (Crude),	0·950–0·965	59·2–60·2
Carbon Bisulphide,	1·293	80·6
Ether,	0·736	45·9
Glycerine,	1·260	78·6
Naptha (Wood),	0·848–0·810	52·9–50·5
Oil, Camphor,	0·910	56·8
,, Castor,	0·969	60·5
,, Linseed,	0·942	58·8
,, Mineral,	0·900–0·925	56·2–57·7
,, Olive,	0·918	57·3
,, Turpentine,	0·873	54·2
Petroleum,	0·878	54·8
Sea Water,	1·025	64·0
Water,	1·000	62·4

Woods.

Substance.	Mass of 1 Cubic Centimetre in Grams.	Mass of 1 Cubic Foot in Lbs.
Alder,	0·42–0·68	26–42
Apple,	0·66–0·84	41–52
Ash,	0·65–0·85	40–53
Beach,	0·70–0·90	43–56
Birch,	0·51–0·77	32–48
Box,	0·95–1·16	59–72
Cedar,	0·49–0·57	30–35
Cherry,	0·70–0·90	43–56
Cork,	0·22–0·26	14–16
Ebony,	1·11–1·33	69–83
Elm,	0·54–0·60	34–37
Hazel,	0·60–0·80	37–49
Laburnum,	0·92	57
Lignum Vitae,	1·17–1·33	73–83
Lime,	0·32–0·59	20–37
Mahogany (Spanish),	0·85	53
Maple,	0·62–0·75	39–47
Oak,	0·60–0·90	37–56
Pear,	0·61–0·73	38–45
Plum,	0·66–0·78	41–49
Poplar,	0·35–0·5	22–31
Satinwood,	0·95	59
Sycamore,	0·40–0·60	24–37
Teak,	0·66–0·98	41–61
Walnut,	0·64–0·70	40–43
Willow,	0·40–0·60	24–37

1 cubic foot of air at 0° C. and under a pressure of 1 atmosphere weighs ·0807 lb.

1 cubic foot of hydrogen at 0° C. and under a pressure of 1 atmosphere weighs ·00557 lb.

Acceleration due to Gravity.

Latitude.	Increase of Velocity per Second due to the Earth's Attraction.		
30°	979·3 cm.	385·5 in.	32·1 ft.
40	980·1	385·9	32·1
50	981·0	386·2	32·2
60	981·9	386·6	32·2

Length of Seconds Pendulum.

Latitude.	Centimetres.	Inches.
30°	99·2	39·1
40	99·3	39·1
50	99·4	39·1
60	99·5	39·2

Pressure.

A standard atmosphere is the pressure of a vertical column of pure mercury, having a height of 760 mm. and temperature 0° C. under standard gravity at latitude 45° and at sea level.

1 standard atmosphere = 1033 grams per sq. cm.
= 14·7 lbs. per sq. in.
= 2116 lbs. per sq. ft.

Pressure of mercurial column 1 inch high
= 34·5 grams per sq. cm.
= 0·491 lbs. per sq. in.

A column of water 2·3 ft. high corresponds to a pressure of 1 lb. per square inch.

Imperial Standard Wire Gauge.

Descriptive Number.	Diameter.		Area of Cross Section.	
	Inches.	Centimetres.	Square Inches.	Square Centimetres.
14	·080	·203	·0050	·0324
16	·064	·162	·0032	·0207
18	·048	·121	·0018	·0116
20	·036	·091	·0010	·0065
22	·028	·071	·0006	·0039
24	·022	·055	·0004	·0024
26	·018	·045	·00025	·0016
27	·016	·041	·00021	·00114
28	·015	·037	·00017	·00111
30	·012	·031	·00012	·00078
32	·011	·027	·00009	·00059
34	·009	·023	·00007	·00043
36	·008	·019	·00004	·00029
38	·006	·015	·00003	·00018
40	·005	·012	·00002	·00012

Angles.

1 second ($''$).
$60'' = 1$ minute ($1'$).
$3600'' = 60' = 1$ degree ($^\circ$).
$324000'' = 5400' = 90^\circ =$ a right angle.
$1296000'' = 21600' = 360^\circ = 4$ right angles $= 1$ rotation.

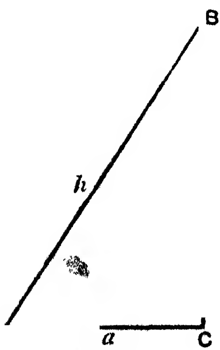


Fig. 112.

The Tangent of an Angle.

If any angle be drawn, such as the acute angle BAC in Fig. 112, and a perpendicular is dropped from the point B to the base AC, then the ratio

$$\frac{\text{perpendicular } BC}{\text{base } AC}$$

is known in trigonometry as the *tangent* of the angle BAC.

The following table shows the value of this ratio for every degree up to 90°.

Table of Tangents.

Angle.	Tangent.	Angle.	Tangent.	Angle.	Tangent.
0°	0				
1	·0175	31°	·6009	61°	1·804
2	·0349	32	·6249	62	1·880
3	·0524	33	·6494	63	1·962
4	·0699	34	·6745	64	2·050
5	·0875	35	·7002	65	2·144
6	·1051	36	·7265	66	2·246
7	·1228	37	·7536	67	2·355
8	·1405	38	·7813	68	2·475
9	·1584	39	·8098	69	2·605
10	·1763	40	·8391	70	2·747
11	·1944	41	·8693	71	2·904
12	·2126	42	·9004	72	3·077
13	·2309	43	·9325	73	3·270
14	·2493	44	·9657	74	3·487
15	·2679	45	1·000	75	3·732
16	·2867	46	1·035	76	4·010
17	·3057	47	1·072	77	4·331
18	·3249	48	1·110	78	4·704
19	·3443	49	1·150	79	5·144
20	·3640	50	1·191	80	5·671
21	·3839	51	1·234	81	6·313
22	·4040	52	1·279	82	7·115
23	·4245	53	1·327	83	8·144
24	·4452	54	1·376	84	9·514
25	·4663	55	1·428	85	11·43
26	·4877	56	1·482	86	14·30
27	·5095	57	1·539	87	19·08
28	·5317	58	1·600	88	28·63
29	·5543	59	1·664	89	57·29
30	·5774	60	1·732	90	∞

Melting Points and Latent Heats of Fusion.

	MELTING POINT.	LATENT HEAT.
Ice,	0°C.	79·2
Beeswax,	61·8	42·3
Spermaceti,	43·9	36·9

Boiling Points and Latent Heats of Vaporization.

	BOILING POINT.	LATENT HEAT.
Steam,	100° C.	536
Alcohol,	78	205
Carbon Bisulphide,	47	84
Benzene,	81	92·9
Turpentine,	159	74
Sulphuric Acid,	338	—
Hydrochloric Acid,	110	—
Nitric Acid,	86	—
Glycerine,	290	—
Ether,	35	90·4

Coefficients of Linear Expansion of Solids.

	EXPANSION PER DEGREE C.
Aluminium,	·000022
Brass,	·000019
Copper,	·000017
Glass (Tube),	·000008
Iron,	·000012
Lead,	·000027
Platinum,	·000009
Silver,	·000019
Slate,	·000010
Zinc,	·000029

Coefficients of Cubical Expansion of Liquids.

Alcohol,	·00109
Benzene,	·00138
Carbon Bisulphide,	·00147
Ether,	·00215

Glycerine,	·00053
Mercury,	·00018
Olive Oil,	·00068
Petroleum,	·00099
Sulphuric Acid,	·00049
Turpentine,	·00105

Coefficients of Expansion of Gases.

	Increase of Pressure at Constant Volume.	Increase of Volume at Constant Pressure.
Hydrogen,	·00367	·00366
Air,	·00366	·00367
Carbon Dioxide,	·00369	·00371

Specific Heats.

Solids.

Aluminium,	·2122
Antimony,	·0486
Beeswax,	·04
Brass,	·0939
Gas Coal,	·3145
Graphite,	·1604
Copper,	·0933
Glass, Crown,	·161
Gold, Flint,	·117
Graphite,	·1604
Iron,	·1124
Lead,	·0315
Magnesium,	·245
Marble,	·2158
Nickel,	·1092
Paraffin,	·622
Platinum,	·0323
Silver,	·0559
Steel,	·118
Sulphur,	·234
Vulcanite,	·3312
Zinc,	·0935

Liquids.

Alcohol, - - - - - -	·615
Benzene, - - - - - -	·423
Ether, - - - - - -	·517
Glycerine, - - - - - -	·376
Mercury, - - - - - -	·033
Olive Oil, - - - - - -	·471
Petroleum, - - - - -	·511
Turpentine, - - - - -	·467

Velocity of Sound.

Substance.	Metres per Second.	Feet per Second.
Aluminium, - - - - -	5104	10740
Brass, - - - - -	3500	11480
Copper, - - - - -	3560	11670
Iron, - - - - -	5130	16820
Platinum, - - - -	2690	8815
Silver, - - - - -	2610	8553
Marble, - - - - -	3810	12500
Slate, - - - -	4510	14800
Glass, - - - - -	5000-6000	16410-19690
Ivory, - - - - -	3013	9886
Ash, along the fibre, - -	4760	15310
,, across the rings, - -	1390	4570
,, along the rings, - -	1260	4140
Oak, - - - - - -	3850	12620
Pine, - - - - - -	3320	10900
Poplar, - - - -	4280	14050
Alcohol, - - - - -	1264	4148
Turpentine, - - - - -	1212	3977
Water, - - - - - -	1437	4714
Temp. 0° C.		
Air, - - - - - -	332	1090
Carbon Dioxide, - - -	262	858
Ammonia, - - - - -	415	1361
Hydrogen, - - - - -	1286	4221
Illuminating Gas, - - -	490	1609
Oxygen, - - - - -	317	1041

Vibration Frequencies of Musical Notes.

	C (*Do*)	D (*Re*)	E (*Mi*)	F (*Fa*)	G (*Sol*)	A (*La*)	B (*Si*)	C (*Do*)
Number of complete vibrations per second (middle octave), - -	256	288	320	340	384	428	480	512
Ratio of vibration numbers, - - - -	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

Indices of Refraction Relative to Air.

Solids.

Diamond, - - - - -	2·42
Flint Glass, - - - -	1·62
Rock Salt, - - - - -	1·54
Crown Glass, - - - -	1·53
Fluor Spar, - - - - -	1·43
Ice, - - - - - - -	1·31

Liquids.

Carbon Bisulphide, - - - - -	1·63
Benzene, - - - - - -	1·49
Olive Oil, - - - - -	1·47
Glycerine, - - - - -	1·47
Turpentine, - - - - -	1·46
Sulphuric Acid, - - - - -	1·42
Alcohol, - - - - - -	1·36
Water, - - - - - -	1·33

Magnetic Declination and Dip (1886).

	Declination W. of North.	Dip.
Aberdeen, - - - - -	20° 16′	71° 12′
Dundee, - - - - -	20 44	70 52
Edinburgh, - - - -	20 47	70 38
Glasgow, - - - - -	21 12	70 45
Newcastle, - - - - -	19 30	69 50
Carlisle, - - - - -	20 26	69 54
Leeds, - - - - -	19 9	69 11
Manchester, - - - -	19 17	69 4
Dublin, - - - - -	21 41	69 16
Bangor, - - - - -	21 44	70 1
Nottingham, - - - -	18 45	68 38
Birmingham, - - - -	18 44	68 21
Cork, - - - - -	22 18	68 46
Oxford, - - - - -	18 34	67 58
London, - - - - -	17 41	67 25
Dover, - - - - -	16 57	67 8
Exeter, - - - - -	19 29	67 26
Falmouth, - - - - -	18 3	66 39

Electrical Resistances of Wires.

	Resistance at 0° C. of a Wire 1 cm. long, 1 sq. cm. in Section.	Resistance at 0° C. of a Wire 1 metre long, 1 mm. in Diameter.
Silver, annealed, - -	$1{\cdot}46 \times 10^{-6}$ ohms.	0·0186 ohms.
,, hard drawn, -	1·58	0·0202
Copper, annealed, - -	1·58	0·0202
,, hard drawn, -	1·61	0·0206
Platinum, - - -	9·03	0·1150
Iron, - - - -	9·69	0·1234
Nickel, - - - -	12·43	0·1583
German Silver, - -	20·89	0·266
Mercury, - - - -	94·07	1·198

A column of pure mercury 106·3 centimetres in length, and 1 sq. millimetre in cross-section, has a resistance of 1 ohm at 0° C.

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